
NOCET DIFFERRE PARATIS

Engraved by Robinson, from a Drawing by Craig.

for the Gallery of Nature & Art.

ICE ISLANDS & CONTINENT IN THE
North Polar Circle.

London, Published by R.N. Rose, 45 Holborn Hill, May 1, 1820.

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OR, A

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A RICH AND COMPREHENSIVE VIEW OF ALL THAT IS INTERESTING AND CURIOUS IN EVERY

Part of the Habitable World.

BY THE

REV. EDW. POLEHAMPTON, & JOHN M. GOOD, F.R.S.

Illustrated by

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GALLERY

OF

NATURE AND ART.

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[CONTINUED.]

CHAPTER XXXIV.

ATMOSPHERICAL DEPARTMENT.

WE now advance to the *atmospherical* phænomena of the science of *Geology*, in the extensive sense in which we have employed this term; and shall proceed to a brief survey of whatever is most curious or worthy of observation in the composition of the Atmosphere; the variation of Climate; the extremes of Heat and Cold; the existence of Electricity and electric Powers, as Thunder and Lighning, Aurora Borealis, Water-spouts; Falling-stars, and Ignes Fatui; Echoes, Wind, Hurricanes, and Storms; the origin of Mist, Dew, Sleet, Snow, Mirages, or Fata Morgana, Meteoric Stones, and various other appearances connected with or dependent upon the preceding; and which collectively constitute *the Science of Meteorology*.

CHAP. XXXV.

GENERAL NATURE OF THE ATMOSPHERE.

THE atmosphere is that invisible elastic fluid which surrounds the earth to an unknown height, and incloses it on all sides. It was thus denominated by the Greeks, in consequence of the vapours which are continually mixing with it, or combined in it*. In contemplating the nature of the atmosphere there are two points of considerable importance to be attended to, respecting which therefore we shall offer a summary of the best established facts and opinions of the present day; and these are the materials that enter into its composition, and the changes to which it is liable.

SECTION I.

Composition of the Atmosphere.

NEITHER the properties nor the composition of the atmosphere seems to have occupied much of the attention of the ancients. Aristotle considered it as one of the four elements, situated between the regions of *water* and *fire*, and mingled with two *exhalations*, the *dry* and *moist*; the first of which occasioned thunder, lightning, and wind; whilst the second produced rain, snow, and hail. The ancients, in general, seem to have considered the blue colours of the sky as essential to the atmosphere; and several of their philosophers believed that it was the constituent principle of other bodies, or at least that air and other bodies are mutually convertible into each other. Thus Lucretius:

> Semper enim quodcunque fluit de rebus, id omne
> Aeris in magnum fertur mare: qui nisi contra
> Corpora retribuat rebus, recreetque fluenteis,
> Omnia jam resoluta forent, et in aera versa.
> Haud igitur cessat gigni de rebus et in res
> Recidere assidue, quoniam fluere omnia constat. *Lib.* v. 274.

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* From ατμος, a vapour, and σφαιρα; a sphere.

All that pours profuse
From things, perpetual, the vast ocean joins
Of air sublime; which if to things again
Paid not, thus balancing the loss sustain'd,
All into air would dissipate and die.
Hence, born from things, to things air still returns
Ceaseless, as prove their fluctuating forms. GOOD.

But these opinions continued in the state of vague conjectures, till the matter was explained by the sagacity of Hales, and of those philosophers who followed his illustrious career.

It was not till the time of Bacon, who first taught mankind to investigate natural phenomena, that the atmosphere began to be investigated with precision. Galileo introduced the study by pointing out its weight; a subject which was soon after investigated completely by Torricelli, Paschal, &c. Its density and elasticity were ascertained by Boyle and the Florence Academicians. Mariotte measured its dilatability; Hooke, Newton, Boyle, Derham, pointed out its relation to light, to sound, and to electricity. Newton explained the effect produced upon it by moisture; from which Halley attempted to explain the changes in its weight indicated by the barometer. But a complete enumeration of the discoveries made upon the atmosphere in general belongs to *pneumatics;* a science which treats professedly of the mechanical properties of air.

The knowledge of the component parts of the atmosphere did not keep pace with the investigation of its mechanical properties. The opinions of the earlier chemists concerning it are too vague and absurd to merit any particular notice. Boyle, however, and his cotemporaries, put it beyond doubt that the atmosphere contained two distinct substances. 1. An elastic fluid distinguished by the name of *air*. 2. Water in a state of vapour. Besides these two bodies, it was supposed that the atmosphere contained a great variety of other substances, which were continually mixing with it from the earth, and which often altered its properties, and rendered it noxious or fatal. Since the discovery of carbonic acid gas by Dr. Black, it has been ascertained that this elastic fluid always constitutes a part of the atmosphere. The constituent parts of the atmosphere therefore are,

1. Air. 3. Carbonic acid gas,
2. Water, 4. Unknown bodies.

These shall form the subject of the four following sections.

[*Thomson's Chemistry.*

SECTION II.

Atmospheric Air.

The word Air seems to have been used at first to denote the atmosphere in general; but philosophers afterwards restricted it to the elastic fluid, which constitutes the greatest and the most important part of the atmosphere, excluding the water and the other foreign bodies which are occasionally found mixed with it. For many years all permanently elastic fluids were considered as air, from whatever combinations they were extricated, and supposed to possess exactly the same properties with the air of the atmosphere. It is true, indeed, that Van Helmont suspected that elastic fluids possessed different properties; and that Boyle ascertained that all elastic fluids are not capable of supporting combustion like air. But it was not till the discoveries of Cavendish and Priestley had demonstrated the peculiar properties of a variety of elastic fluids, that philosophers became sensible that there existed various species of them. In consequence of this discovery, the word *air* became generic, and was applied by Priestley, and the British and Swedish philosophers in general, to all permanently elastic fluids, while the air of the atmosphere was distinguished by the epithets of *common* or *atmospheric* air: but Macquer thought proper to apply the term *gas,* first employed by Van Helmont, to all permanently elastic fluids except common air, and to confine the term *air* to this last fluid. This innovation was scarcely necessary; but as it has now been generally adopted, it will be proper to follow it. By the word *air,* then, in this Section, is meant only common *air,* or the fluid which forms by far the greatest part of the atmosphere.

The foreign bodies which are mixed or united with air in the atmosphere are so minute in quantity compared to it, that they have no very sensible influence on its properties. We may therefore consider atmospheric air, when in its usual state of dryness, as sufficiently pure for examination.

1. Air is an elastic fluid, invisible indeed, but easily recognised by its properties. Its specific gravity, according to the experiments of Sir George Shuckburgh, when the barometer is at 30 inches, and the thermometer between 50° and 60°, is usually reckoned 1·000: it is 816 times lighter than water. One hundred cubic inches of air weigh 31 grains troy.

But as air is an elastic fluid, and compressed at the surface of the earth by the whole weight of the incumbent atmosphere, its density diminishes according to its height above the surface of the earth. From the experiments of Paschal, Deluc, General Roy, &c. it has been ascertained, that the density diminishes in the ratio of the compression. Consequently the density decreases in a geometrical progression, while the heights increase in an arithmetical progression.

Buguer had suspected, from his observations made on the Andes, that at considerable heights the density of the air is no longer proportional to the compressing force *; but the experiments of Saussure junior, made upon Mount Rose, have demonstrated the contrary †.

2. Although the sky is well known to have a blue colour, yet it cannot be doubted that air itself is altogether colourless and invisible. The blue colour of the sky is occasioned by the vapours which are always mixed with air, and which have the property of reflecting the blue rays more copiously than any other. This has been proved by the experiments which Saussure made with his *cyanometer* at different heights above the surface of the earth. This instrument consisted of a circular band of paper, divided into fifty-one parts, each of which was painted with a different shade of blue; beginning with the deepest mixed with black, to the lightest mixed with white. He found that the colour of the sky always corresponded with the deepest shade of blue the higher the observer is placed above the surface; consequently, at a certain height, the blue will disappear altogether, and the sky appear black; that is to say, will reflect no light at all. The colour becomes always lighter in proportion to the vapours mixed with the air. Hence it is evidently owing to them ‡.

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* Mem. Par. 1753. p. 515. † Jour. de Phys. xxxvi. 98.

‡ Saussure, Voyages dans les Alpes, iv. 288.

3. For many ages air was considered as an element or simple substance. For the knowledge of its component parts, we are indebted to the labours of those philosophers in whose hands chemistry advanced with such rapidity during the last forty years of the 18th century. The first step was made by Dr. Priestley in 1774, by the discovery of oxygen gas. This gas, according to the prevailing theory of the time, he considered as air totally deprived of phlogiston; azotic gas, on the other hand, was air saturated with phlogiston. Hence he considered common air as oxygen gas combined with an indefinite portion of phlogiston, varying in purity according to that portion; being always the purer the smaller a quantity of phlogiston it contained.

While Dr. Priestley was making experiments on oxygen gas, Scheele proceeded on the analysis of air in a different manner. He observed that the liquid sulphurets, phosphorus, and various other bodies, when confined along with air, have the property of diminishing its bulk; and this diminution always amounts to a certain proportion, which he found to be between a third and a fourth part of the whole. The residuum was unfit for supporting flame, and was not diminished by any of the processes which diminish common air. To this residuum he gave the name of *foul air*. From these experiments, he concluded that air is a compound of two different elastic fluids: namely, *foul air*, which constitutes more than two-thirds of the whole, and *another air*, which is alone capable of supporting flame and animal life. This last air he extricated from nitre by heat, from the black oxide of manganese, and from other substances, and gave it the name of *empyreal air*. He showed that a mixture of two parts of foul air and one part of empyreal air, possesses the proportion of common air*.

The foul air of Scheele was the same with the phlogisticated air of Priestley, or with what is now known by the name of *azotic gas*. His empyreal air is the same with the dephlogisticated air of Priestley, or with what is at present called *oxygen gas*. According to him, therefore, air is a compound of two parts of azotic and one part of oxygen gas. He accounted for the diminution of air by the liquid sulphurets and other similar bodies by

* Scheele on *Air and Fire*, p. 7, &c. Engl. Transl.

his theory of the composition of caloric, which he considered as a compound of phlogiston and oxygen gas. According to him, the phlogiston of the sulphuret combines with the oxygen of the air, and passes through the vessels in the state of caloric, while the azotic gas, which has no affinity for caloric, is left behind.

While Scheele was occupied with his experiments on air, Lavoisier was assiduously employed on the same subject, and was led by a different road to precisely the same conclusion as Scheele. By oxidizing mercury in a vessel filled with common air, and heated to the boiling point of mercury, he abstracted the greater part of its oxygen gas; and by heating the red oxide thus formed, he reconverted it into mercury, while at the same time a quantity of oxygen gas was extricated. The residuum in the first experiment possessed the properties of azotic gas; but when the oxygen gas extricated from the mercury was added to it, the mixture assumed again the properties of common air. Hence he concluded that air is composed of azotic gas and oxygen; and from a variety of experiments he determined the proportions to be 73 parts of azotic gas and 27 parts of oxygen gas. He demonstrated, too, that when air is diminished by liquid sulphurets, metals, &c. the oxygen gas which is abstracted combines with the sulphurets, &c. and converts them into acids or oxides according to their respective nature.

Air, then, is a compound of oxygen and azotic gas: but it becomes a question of considerable consequence to determine the proportion of these two ingredients, and to ascertain whether that proportion is in every case the same. Since azotic gas, one of the component parts of that fluid, cannot be separated by any substance with which chemists are acquainted, the analysis of air can only be attempted by exposing it to the action of those bodies which have the property of absorbing its oxygen. By these bodies the oxygen gas is separated, and the azotic gas is left behind, and the proportion of oxygen may be ascertained by the diminution of bulk; which being once known, it is easy to ascertain the proportion of azotic gas, and thus to determine the exact relative quantity of the component parts of air.

After the composition of the atmosphere was known to philosophers, it was taken for granted that the proportion of its oxygen

varies at different times and in different places; and that upon this variation depended the purity or noxious qualities of air. Hence it became an object of the greatest importance to get possession of a method to determine readily the quantity of oxygen in a given portion of air. Accordingly various methods were proposed, all of them depending upon the property which many bodies possess, of absorbing the oxygen of the air without acting upon its azote. These bodies were mixed with a certain known quantity of atmospheric air in graduated glass vessels inverted over water, and the proportion of oxygen was determined by the diminution of bulk. These instruments received the name of *eudiometers*, because they were considered as measures of the purity of air. The eudiometers proposed by different chemists may be reduced to five.

1. The first eudiometer was made in consequence of Dr. Priestley's discovery, that when nitrous gas is mixed with air over water, the bulk of the mixture diminishes rapidly, in consequence of the combination of the gas with the oxygen of the air and the absorption of the nitric acid thus formed by the water. When nitrous gas is mixed with azotic gas, no diminution at all takes place. When it is mixed with oxygen gas in proper proportions, the absorption is complete. Hence it is evident, that in all cases of a mixture of these two gases the diminution will be proportional to the quantity of the oxygen. Of course it will indicate the proportion of oxygen in air; and by mixing it with different portions of air, will indicate the different quantities of oxygen which they contain, provided the component parts of air be susceptible of variation. Dr. Priestley's method was to mix together equal bulks of air and nitrous gas in a low jar, and to transfer the mixture into a narrow graduated glass tube about three feet long, in order to measure the diminution of bulk. He expressed this diminution by the number of hundred parts remaining. Thus, suppose he had mixed together equal parts of nitrous gas and air, the sum total of this mixture was 200 (or 2·00): suppose the residuum when measured in the graduated tube to amount to 104 (or 1·04), and of course that 96 parts of the whole had disappeared, he denoted the purity of the air thus tried by 104. A more convenient instrument was invented by Dr. Falconer of Bath; and Fontana greatly im-

proved this method of measuring the purity of air. A description of his eudiometer was published by Ingenhousz in the first volume of his Experiments; but it was Mr. Cavendish who first brought this eudiometer to such a state of precision as to be enabled to ascertain correctly the constituents of air. His method was to put 125 measures of nitrous gas into a glass vessel, and to let up into it very slowly 100 measures of the air to be examined, agitating the vessel containing the nitrous gas during the whole time. The diminution of bulk when the process was conducted in this way was almost uniform. The greatest was 110, the least 106·8; the mean 108·2. The variation he found to depend, not upon the air examined, but upon the state of the water in which the experiment was made. If this experiment was reversed, by letting up the nitrous gas to common air, he used 100 measures of each, and the diminution in that case was only 90 measures.

This constancy in the diminution of the bulk of all the different specimens of common air examined, induced Mr. Cavendish to conclude that the proportion between the oxygen and azote in common air does not vary. To find the absolute quantity of oxygen in air, he mixed together oxygen gas and azote in various proportions, and at last found that a mixture of 10 measures of the purest oxygen which he could procure with 38 measures of azote, was just as much diminished by the nitrous gas as the same bulk of common air. Hence he concluded that air is composed of 10 parts by bulk of oxygen and 38 of azote, which gives us for its composition *per cent.*

79·16 azote
20·84 oxygen

100·00

or very nearly 21 *per cent.* of oxygen gas*.

Other philosophers, who did not pay that rigid attention to precision which characterises all Mr. Cavendish's experiments, obtained variable results from the nitrous gas eudiometer. Most of the circumstances which occasion the variation were pointed out by Cavendish; but they seem to have escaped the observation of succeeding chemists. Humboldt's attempt to render the eudiome-

* Phil. Trans. 1808, p. 107.

ter of Fontana accurate did not succeed*. But Mr. Dalton has lately explained the anomalies in a very luminous manner. According to this philosopher, oxygen gas and nitrous gas are capable of uniting in two proportions: 21 measures of oxygen gas uniting either with 36 measures of nitrous gas, or with twice 36, = 72 measures. Both of these compounds are soluble in water. If the tube be wide, a considerable portion of nitrous gas comes at once in contact with the oxygen. Hence the latter gas combines with a maximum of nitrous, especially if agitation be employed. In a narrow tube the oxygen combines with the minimum of nitrous gas, provided no agitation be employed, and the residue be poured soon into another vessel. When intermediate proportions are used, the absorption will be immediate. Mr. Dalton recommends a narrow tube; the nitrous gas is only to be in the proportion requisite to form the minimum combination; no agitation is to be employed: and when the diminution is completed, the gas must be transferred to another tube. To 100 measures of air add about 36 of nitrous gas; note the diminution of bulk, and multiply it by 7-19ths; the product gives the bulk of oxygen in the air examined†.

In order to get rid of the anomalies which had perplexed former experimenters, Mr. Davy proposed to employ the nitrous gas in a different state. He caused sulphate or muriate of iron to absorb this gas to saturation, and employed the dark brown liquid thus obtained to deprive air of its oxygen. A small graduated glass tube, filled with the air to be examined, is plunged into the nitrous solution, and moved a little backwards and forwards. The whole of the oxygen is absorbed in a few minutes. The state of greatest absorption ought to be marked, as the mixture after emits a little gas, which would alter the result. By means of this Mr. Davy examined the air at Bristol, and found it always to contain about 0·21 of oxygen. Air sent to Dr. Beddoes from the coast of Guinea gave exactly the same result.

2. For the second kind of eudiometer we are indebted to Scheele. It is merely a graduated glass vessel, containing a given quantity of air exposed to newly prepared liquid alkaline or earthy sulphurets, or to a mixture of iron filings and sulphur, formed into a paste with water. These substances absorb the whole of the

* Ann. xxvii. p.

† Dalton, Phil. Mag. xxiii. 351.

oxygen of the air, which converts a portion of the sulphur into an acid. The oxygen contained in the air thus examined, is judged of by the diminution of bulk which the air has undergone. This method is not only exceedingly simple, but it acquires very little address, and yet is susceptible of as great accuracy as any other whatever. The only objection to which it is liable is its slowness; for when the quantity of air operated on is considerable, several days elapse before the diminution has reached its maximum.

But this objection has been completely obviated by Mr. De Marti, who has brought Scheele's eudiometer to a state of perfection. He found that a mixture of iron filings and sulphur does not answer well, because it emits a small quantity of hydrogen gas, evolved by the action of the sulphuric acid formed upon iron; but the hydrogureted sulphurets, formed by boiling together sulphur and liquid potash or lime water, answered the purpose perfectly. These substances, indeed, when newly prepared, have the property of absorbing a small portion of azotic gas; but they lose this property when saturated with that gas, which is easily effected by agitating them for a few minutes with a small portion of atmospheric air. His apparatus is merely a glass tube, ten inches long, and rather less than half an inch in diameter, open at one end, and hermetically sealed at the other. The close end is divided into 100 equal parts, having an interval of one line between each division. The use of this tube is to measure the portion of air to be employed in the experiment. The tube is filled with water; and by allowing the water to run out gradually while the tube is inverted, and the open end kept shut with the finger, the graduated part is exactly filled with air. These hundred parts of air are introduced into a glass bottle filled with liquid sulphuret of lime previously saturated with azotic gas, and capable of holding from two to four times the bulk of the air introduced. The bottle is then to be corked with a ground glass stopper, and agitated for five minutes. After this the cork is to be withdrawn while the mouth of the phial is under water; and for the greater security, it may be corked and agitated again. After this, the air is to be again transferred to the graduated glass tube, in order to ascertain the diminution of its bulk*.

* Jour. de Phys. lii. 176.

Air examined by this process suffers precisely the same diminution in whatever circumstances the experiments are made: no variation is observed whether the wind be high or low, or from what quarter soever it blows; whether the air tried be moist or dry, hot or cold; whether the barometer be high or low. Neither the season of the year, nor the situation of the place, its vicinity to the sea, to marshes, or to mountains, make any difference. Mr. De Marti found the diminution always between 0·21 and 0·23.

3. The third kind of eudiometer was proposed by Volta. The substance employed by that philosopher to separate the oxygen from the air was hydrogen gas. His method was to mix given proportions of the air to be examined and hydrogen gas in a graduated glass tube; to fire the mixture by an electric spark; and to judge of the purity of the air by the bulk of the residuum. This method has been lately examined by Gay Lussac and Humboldt. They have found it susceptible of great precision. It is one of the simplest and most elegant methods of estimating the proportion of oxygen air. When 100 measures of hydrogen are mixed with 200, or any greater bulk of oxygen, up to 900 measures, the diminution of bulk after detonation is always 146 measures. The same diminution is obtained if the hydrogen be increased up to a certain quantity. The result of their trials is, that 100 measures of oxygen gas require 200 of hydrogen for complete combustion, which coincides very well with the trials previously made in this country. Hence the method of using this eudiometer is very simple: Mix together equal bulks of the air to be examined and of hydrogen gas, ascertain the diminution of bulk after combustion, divide it by three, the quotient represents the number of measures of oxygen in the air. A great number of trials, in different seasons of the year, of mixtures of 200 measures of air and as much hydrogen, gave almost uniformly a diminution of bulk amounting to 126 measures. Now the third of 126 is 42, the quantity of oxygen is 200 measures of air. Hence 100 parts of air, according to these trials, contain 21 of oxygen*.

4. In the fourth kind of eudiometer, the abstraction of the oxygen of air is accomplished by means of phosphorus. This eudiometer was first proposed by Achard†. It was considerably

* Jour. de Phys. lx. 129. † Ibid. 1784, vol. i.

improved by Reboul*, and by Seguin and Lavoisier†; but Berthollet‡ has lately brought it to a state of perfection.

Instead of the rapid combustion of phosphorus, this last philosopher has substituted its spontaneous combustion, which absorbs the oxygen of air completely; and when the quantity of air operated on is small, the process is over in a short time. The whole apparatus consists in a narrow graduated tube of glass, containing the air to be examined, into which is introduced a cylinder of phosphorus fixed upon a glass rod, while the tube stands inverted over water. The phosphorus should be so long as to traverse nearly the whole of the air. Immediately white vapours rise from the phosphorus, and fill the tube. These continue till the whole of the oxygen combines with phosphorus. They consist of phosphorus acid, which falls by its weight to the bottom of the vessel, and is absorbed by the water. The residuum is merely the azotic gas of the air, holding a portion of phosphorus in solution. Berthollet has ascertained, that by this foreign body its bulk is increased 1-40th part. Consequently the bulk of the residuum, diminished by 1-40th, gives us the bulk of the azotic gas of the air examined; which bulk, substracted from the original mass of air, gives us the proportion of oxygen gas contained in it §.

All the different experiments which have been made by means of this eudiometer agree precisely in their result, and indicate that the proportions of the ingredients of air are always the same; namely, about 0·21 parts of oxygen gas, and 0·79 of azotic gas. Berthollet found these proportions in Egypt and in France, and they have been found constantly in Edinburgh, in all the different seasons of the year.

Thus it appears, that whatever method is employed to abstract oxygen from air, the result is uniform, provided the experiment may be precisely made. They all indicate that common air consists very nearly of 21 parts of oxygen and 79 of azote. Scheele and Lavoisier found 27 *per cent.* of oxygen, but their methods

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* Ann. de Chem. xiii. 38.

† Ibid. ix. 293.

‡ Ibid. xxxiv. 73, and Jour. de l'Ecole Polytechn. I. iii. 274.

§ A very convenient apparatus for making eudiometrical experiments has lately been invented by Mr. Pepys, and described by him in the Phil. Trans. for 1807.

were not susceptible of precision. Air, then, does not vary in its composition; the proportion between its constituents is constant in all places and all heights. Gay Lussac examined air brought from the height of more than 21,000 feet above Paris, and found it precisely the same as the air at the earth's surface*.

But 21 cubic inches of oxygen gas weigh 9·14 grains, and 79 inches of azote weigh 23·9686 grains. These added together amount to 31·1086 grains, which ought to be the weight of 100 inches of common air. But this is somewhat greater than the weight of 100 inches of air, according to Sir John Shuckburgh Evelyn's experiment, who found it only 31·0197 grains. The difference is not great, and is probably owing to a small error in the specific gravities of the different gases. According to this estimate, 100 parts of air are composed by weight of

22·91 oxygen
77·09 azote

100·000

Mr. Dalton considers air as merely a mechanical mixture of the two gases of which it is compounded. But all other chemists consider it as a chemical compound: most of them as a compound of azote and oxygen holding each other in dissolution.

[*Thomson's Chemistry.*

SECTION III.

Atmospheric Water.

THAT the atmosphere contains water has been always known. The rain and dew which so often precipitate from it, the clouds and fogs with which it is often obscured, and which deposit moisture on all bodies exposed to them, have demonstrated its existence in every age. Even when the atmosphere is perfectly transparent, water may be extracted from it in abundance by certain substances. Thus, if concentrated sulphuric acid be exposed to air, it gradually attracts so much moisture, that its weight is increased more than three times: it is converted into diluted acid, from which the water may be separated by distillation. Substances

* Phil. Mag. xxi. 225.

which have the property of abstracting water from the atmosphere have received the epithet of *hygroscopic*, because they point out the presence of that water. Sulphuric acid, the fixed alkalies, muriate of lime, nitrate of lime, and in general all deliquescent salts, possess this property. The greater number of animal and vegetable bodies likewise possess it. Many of them take water from moist air, but give it out again to the air when dry. These bodies augment in bulk when they receive moisture, and diminish again when they part with it. Hence some of them have been employed as *hygrometers*, or measures of the quantity of moisture contained in the air around them. This they do by means of the increase or diminution of their length, occasioned by the addition or abstraction of moisture. This change of length is precisely marked by means of an index. The most ingenious and accurate hygrometers are those of Saussure and Deluc. In the first, the substance employed to mark the moisture is a human hair, which by its contractions and dilatations is made to turn round an index. In the second, instead of a hair, a very fine thin slip of whalebone is employed. The scale is divided into 100°. The beginning of the scale indicates extreme dryness, the end of it indicates extreme moisture. It is graduated by placing it first in air made as dry as possible by means of salts, and afterwards in air saturated with moisture. This gives the extremes of the scale, and the interval between them is divided into 100 parts.

Since it cannot be doubted that the atmosphere always contains water, there are only two points which remain to be investigated: 1. The state in which that water exists in air; 2. The quantity which a given bulk contains.

I. With respect to the state in which water exists in air, two opinions have been formed, each of which has been supported by very able philosophers. 1. Water may be dissolved in air in the same manner as a salt is held in solution by water. 2. It may be mixed with air in the state of steam or vapour, after having been converted into vapour.

1. The first of these opinions was hinted at by Dr. Hooke, in his "Micrographia," and afterwards proposed by Dr. Halley; but it was much more fully developed by Mr. Le Roy, of Montpelier, in 1751. Dr. Hamilton of Dublin made known the same theory about the same time. The phænomena in general coincide remarkably well with this theory. The quantity of water which

air is capable of holding in solution is increased by every augmentation of temperature, and diminished by cold, which is precisely analagous to almost all other solvents. These analogies, and several others which will easily suggest themselves to the reader, have induced by far the greater number of philosophers to adopt this opinion.

2. The second theory, namely, that water exists in air in the state of vapour, has been embraced by Deluc in his last treatise on Meteorology; at least his reasoning appears to me to lead to that conclusion. But it is to Mr. Dalton that we are indedted for the most precise information on the subject*. The following reasons put the truth of this opinion almost beyond the reach of controversy.

In the *first* place, it cannot be doubted that the water which exists in air, is derived originally from the waters on the surface of the earth, which are exposed to the action of the atmosphere. Accordingly we find that water, when exposed to the air, suffers a gradual diminution of bulk, and at last disappears altogether. This diminution of the water may be owing, either to its gradual solution in air, or to its conversion into vapour. The last is the common opinion, as the phenomenon is in common language ascribed to the *evaporation* of the water. When water is placed in an exhausted receiver, it diminishes in bulk even more rapidly than in the open air. In this case, as no air is present, we can only ascribe the diminution of bulk to the conversion of the water into vapour. Accordingly we find, upon examination, that the receiver is actually filled with water in the state of vapour. The presence of this vapour very soon, by its elasticity, puts an end to the evaporation of the water. Now, since water disappears equally whether air be present or not, and exactly in the same manner, it is reasonable to ascribe its disappearing in both cases to the same cause. But in the exhausted receiver it is converted into vapour. Hence it is probable that it is converted into vapour also in the open air; and if so, it must exist in air in the state of vapour.

In the *second* place, if the disappearing of water exposed to the open air were owing to solution and not to evaporation, it ought certainly to disappear more rapidly when it is exposed to the action of a great quantity of air then when to a small quantity; for the

* Manchester Memoirs, v. p. 517.

quantity of any body dissolved is always proportional to the quantity of the solvent. But the very contrary is what actually takes place with respect to the water contained in the air. Saussure has proved that water evaporates much faster at great heights than at the surface of the earth, even when the temperature and the moisture of the air in both places are the same. By comparing a set of experiments made upon the Col-du-Geant, at the height of 11,275 feet above the level of the sea, with a similar set made at Geneva, 1324 feet above the level of the sea, he ascertained, that supposing the temperature and the dryness of the air in both places the same, the quantity of water evaporated at Geneva is to that evaporated on the Col-du-Geant in the same time and same circumstances as 37 to 84, or nearly as 3 : 7. Now the air on the Col-du-Geant is about one-third rarer than at Geneva; so that the diminution of about one-third in the density of the air more than double the rate of evaporation*. This is precisely what ought to be the case, provided the water which disappears mixes with the air in the state of vapour only; but the very contrary ought to hold, if the water disappeared in consequence of the solvent power of air.

In the *third* place, it has been demonstrated by Dr. Black, that vapour is water combined with a certain dose of caloric. Consequently when water is converted into vapour, a certain portion of caloric combines with it and disappears. If, therefore, there is the same waste of caloric whenever water passes from a liquid state, and enters into the atmosphere as a component part, we have reason to conclude that it enters into the atmosphere only in the state of vapour. But it is a well-known fact that cold is always generated during spontaneous evaporation; that is to say, that the water as it disappears carries off with it a quantity of caloric. It is well known, that when a wet body is exposed to the air, its temperature is lowered by the evaporation which takes place upon its surface. Hence, in warm countries, water is cooled by putting it into porous vessels, and exposing it to the air. —The water penetrates through the vessels, evaporates from their surface, and carries off so much heat, as even in some cases to freeze the water in the vessel. Saussure observed, that the evaporation from the surface of melted snow caused it to freeze

* Saussure's Voyages dans les Alpes, iv. 263.

again when the temperature of the surrounding air was 4·5° above the freezing point. Dr. Black has rendered it probable that the quantity of caloric which disappears during spontaneous evaporation, is as great as that which is necessary to convert water into steam. We have a right then to conclude, that water, when it evaporates spontaneously, is always converted into vapour, and of course that it is only in that state that it enters into the atmosphere.

In the *fourth* place, Mr. Dalton has demonstrated, that the water which exists in air, possesses precisely the same degree of elasticity that it does when in the state of a vapour in a vacuum at the same temperature. Hence it follows irresistibly that it exists in air, not in the state of water, but of an elastic fluid or vapour.

We are authorised to conclude, then, that the water which exists in the atmosphere is in the state of vapour. This vapour is held in solution by the air precisely as one species of gas is by another. Hence the reason why it is so difficult to separate it, and why it is capable of undergoing a considerable degree of compression without assuming the form of a liquid.

II. Many attempts has been made to measure the quantity of water contained in air; but Saussure was the first who attained any thing like precision. This ingenious philosopher has shown, in his Hygrometrical Essays, that an English cubic foot of air, when saturated with water, at the temperature of 66°, contains only about eight grains troy of that liquid, or about 1-67th of its weight. But the experiment of Mr. Dalton was susceptible of more precision. As the greatest part of the water of the atmosphere is in the state of vapour, the elasticity of which depends upon the temperature, it is obvious that this elasticity, provided it can be ascertained, must measure the quantity of vapour which exists in the atmosphere, the temperature being the same. The elasticity or force of vapour was determined by this ingenious philosopher in the following manner, which had been originally contrived by Le Roy: he took a tall cylindrical glass jar, dry on the outside, and filled it with cold spring water fresh from the well: if dew was immediately formed on the outside, he poured the water out, let it stand the while to increase in temperature, dried the outside of the glass well with a linen cloth, and then

poured the water in again. This operation was to be continued till the dew ceased to be formed, and then the temperature of the water was observed; and opposite to it in the Table was found the force of vapour in the atmosphere. This experiment must be conducted in the open air, or at a window; because the air within is generally more humid than that without. Spring water is generally about 50°, and will mostly answer the purpose of the three hottest months in the year: in other seasons an artificial cold mixture is required.

From Dalton's experiments it follows that the quantity of vapour in the atmosphere is variable in quantity. In the torrid zone its force varies from 0·6, to one inch of mercury. In Britain it seldom amounts to 0·6, but is often as great as 0·5 during summer. In winter it is often as low as 0·1 of an inch of mercury *.

These facts would enable us to ascertain the absolute quantity of vapour contained in the atmosphere at any given time, provided we were certain that the density and elasticity of vapours follow precisely the same law as that of gases, as is extremely likely to be the case. If so, the vapour will vary from $\frac{1}{60}$ to $\frac{1}{100}$ part of the atmosphere. Dalton supposes that the medium quantity of vapour held in solution at once in the atmosphere may amount to about $\frac{1}{70}$ of its bulk †.

[*Thomson's Chemistry.*

SECTION IV.

Atmospheric Carbonic Acid.

The existence of carbonic acid gas as a constituent part of the atmosphere, was observed by Dr. Black immediately after he had ascertained the nature of that peculiar fluid. If we expose a pure alkali or alkaline earth to the atmosphere, it is gradually converted into a carbonate by the absorption of carbonic acid gas. This fact, which had been long known, rendered the inference, that carbonic acid gas existed in the atmosphere, unavoidable, as soon as the difference between a pure alkali and its carbonate had

* Dalton, Manchester Memoirs, V. 547.

† Phil. Mag. xxiii. 353.

been ascertained to depend upon that acid. Not only alkalies and alkaline earths absorb carbonic acid when exposed to the air, but several of the metallic oxides also. Hence the reason that we so often find the native oxides in the state of carbonates. Thus *rust* is always saturated with carbonic acid.

Carbonic acid gas not only forms a constituent part of the atmosphere near the surface of the earth, but at the greatest heights which the industry of man has been able to penetrate. Saussure found it at the top of Mount Blanc, the highest point of the old continent; a point covered with eternal snow, and not exposed to the influence of vegetables or animals. Lime-water, diluted with its own weight of distilled water, formed a pellicle on its surface after an hour and three quarters exposure to the open air on that mountain; and slips of paper moistened with pure potash, acquired the property of effervescing with acids after being exposed an hour and a half in the same place *. Now this was the height no less than 15,668 feet above the level of the sea. Humboldt has more lately ascertained the existence of this gas in air brought by Mr. Garnerin from a height not less than 4280 feet above the surface of the earth, to which height he had risen in an air-balloon †. This fact is a sufficient proof that the presence of carbonic acid in air does not depend upon the vicinity of the earth.

The difficulty of separating this gas from air has rendered it difficult to determine with accuracy the relative quantity of it in a given bulk of air. From the experiments of Humboldt, it appears to vary from 0·005 to 0·01.

Mr. Dalton's experiments give the quantity much smaller. He found, that if a glass vessel filled with 102,400 grains of rain water be emptied in the open air, 125 grains of lime water be poured in, and the mouth then closed; by sufficient time and agitation, the whole of the lime-water is just saturated with the carbonic acid which it finds in the inclosed volume of the air: but 125 measures of lime water require 70 measures of carbonic acid gas to saturate them. Hence he concludes, that air contains only 1-1400th of its bulk of carbonic acid ‡.

From the previous experiments of Mr. Cavendish, however, we

* Saussure's Voyages, iv. 199. † Jour. de Phys. xlvii. 202.
‡ Phil. Mag. xxiii. 354.

learn that lime-water is not capable of depriving air of the whole of its carbonic acid. A portion still remains, which can only be separated either by milk of lime, or by repeated washings with new doses of lime-water. Hence the quantity of carbonic acid in air must be considerably greater than it was found by Dalton. I do not know exactly the meaning of *lime-water being* just *saturated,* unless it signifies that it refuses to absorb any more gas. In that case the whole of the lime is held in solution by the acid. It must be difficult to ascertain the exact point of saturation according to this sense of the word. We may conclude, however, from Dalton's experiment, that the bulk of carbonic acid in air does not much exceed 1·1000th of the atmosphere; but it is liable to variation from different circumstances. Immense quantities of carbonic acid must be constantly mixing with the atmosphere, as it is formed by the respiration of animals, by combustion, and several other processes which are going on continually. The quantity, indeed, which is daily formed by these processes is so great, that at first sight it appears astonishing that the gas does not increase rapidly. The consequence of such an increase would be fatal, as air containing 0·1 of carbonic acid extinguishes light, and is noxious to animals. But we shall find reason afterwards to conclude, that this gas is decomposed by vegetables as rapidly as it is formed.

[*Thomson's Chemistry.*

SECTION V.

Atmospheric unknown Bodies.

From the three preceding Sections, we see that the atmosphere consists chiefly of three distinct elastic fluids united together by chemical affinity; namely, air, vapour, and carbonic acid gas; differing in their proportions at different times and in different places; but that the average proportion of each is

98·9	air
1·0	vapour
0·1	carbonic acid.
100·0	

But besides these bodies, which may be considered as the constituent parts of the atmosphere, the existence of several other bodies has been suspected in it. I do not mean in this place to include among those bodies electric matter, or the substance of clouds and fogs, and those other bodies which are considered as the active agents in the phænomena of meteorology, but to confine myself merely to those foreign bodies which have been occasionally found or suspected in air. Concerning these bodies, however, very little satisfactory is known at present, as we are not in possession of instruments sufficiently delicate to ascertain their presence. We can indeed detect several of them actually mixing with air, but what becomes of them afterwards we are unable to say.

1. Hydrogen gas is said to have been found in air situated near the crater of volcanoes, and it is very possible that it may exist always in a very small proportion in the atmosphere; but this cannot be ascertained till some method of detecting the presence of hydrogen combined with a great proportion of air be discovered. From the experiments of Gay Lussac and Humboldt, it appears that air does not contain so much as 3-1000th parts hydrogen.

2. Carburated hydrogen gas is often emitted by marshes in considerable quantities during hot weather. But its presence has never been detected in air; so that in all probability it is again decomposed by some unknown process.

3. Oxygen gas is emitted by plants during the day. We shall afterwards find reason to conclude that this is in consequence of the property which plants have of absorbing and decomposing carbonic acid gas. Now, as this carbonic acid is formed at the expense of the oxygen of the atmosphere, as this oxygen is again restored to the air by the decomposition of the acid, and as the nature of atmospheric air remains unaltered, it is clear that there must be an equilibrium between these two processes; that is to say, all the carbonic acid formed by combustion must be again decomposed, and all the oxygen abstracted must be again restored. The oxygen gas which is thus continually returning to the air, keeps its component parts always at the same ratio.

4. The smoke and other bodies which are continually carried into the air by evaporation, &c. are probably soon deposited again,

and cannot therefore be considered with propriety as forming parts of the atmosphere. But there is another set of bodies which are occasionally combined with air, and which, on account of the powerful action which they produce on the human body, have attracted a great deal of attention. These are known by the names of matters of *contagion*.

That there is a difference between the atmosphere in different places, as far as respects its effects upon the human body, has been considered as an established point in all ages. Hence some places have been celebrated as healthy, and others avoided as pernicious to the human constitution. It is well known that in pits and mines the air is often in such a state as to suffocate almost instantaneously those who attempt to breathe it. Some places are haunted by peculiar diseases. It is known that those who frequent the apartments of persons ill of certain maladies, are extremely apt to catch the infection: and in prisons and other places, where crowds of people are confined together, when diseases once commence, they are wont to make dreadful havoc. In all these cases, it has been supposed that a certain noxious matter is dissolved by the air, and that it is the action of this matter which produces the mischief.

This noxious matter is in many cases readily distinguished by the peculiarly disagreeable smell which it communicates to the air. No doubt this matter differs according to the diseases which it communicates, and the substance from which it has originated. Morveau lately attempted to ascertain its nature; but he soon found the chemical tests hitherto discovered altogether insufficient for that purpose. He has put it beyond a doubt, however, that the noxious matter which rises from putrid bodies is of a compound nature; and that it is destroyed together by certain agents, particularly by those gaseous bodies which readily part with their oxygen. He exposed air infected by putrid bodies to the action of various substances; and he judged of the result by the effect which these bodies had in destroying the fetid smell of the air. The following is the result of his experiments.

1. Odorous bodies, such as benzoin, aromatic plants, &c. have no effect whatever. 2. Neither have the solutions of myrrh, benzoin, &c. in alcohol, though agitated in infected air. 3. Pyroligneous acid is equally inert. 4. Gunpowder, when fired in in-

fected air, displaces a portion of it; but what remains still retains its fetid odour. 5. Sulphuric acid has no effect; sulphureous acid weakens the odour, but does not destroy it. 6. Vinegar diminishes the odour, but its action is slow and incomplete. 7. Acetic acid acts instantly, and destroys the fetid odour of infected air completely. 8. The fumes of nitric acid, first employed by Dr. Carmichael Smith, are equally efficacious. 9. Muriatic acid gas, first pointed out as a proper agent by Morveau himself, is equally effectual. 10. But the most powerful agent is oxmuriatic acid gas, first proposed by Mr. Cruikshanks, and now employed with the greatest success in the British Navy and Military Hospitals.

Thus there are four substances which have the property of destroying contagious matter, and of purifying the air: but acetic acid cannot easily be obtained in sufficient quantity, and in a state of sufficient concentration, to be employed with advantage. Nitric acid may be attended with some inconvenience, because it is almost always contaminated with nitrous gas. Muriatic acid and oxymuriatic acid are not attended with these inconveniences; the last deserves the preference, because it acts with greater energy and rapidity. All that is necessary is to mix together two parts of common salt with one part of the black oxide of manganese, to place the mixture in an open vessel in the infected chamber, and to pour upon it two parts of sulphuric acid. The fumes of oxymuriatic acid are immediately exhaled, fill the chamber, and destroy the contagion. Or the oxymuriate of lime, sold for the purposes of the bleacher, may be mixed with sulphuric acid, and placed in the infected apartment.

[*Thomson's Chemistry.*

SECTION VI.

Variation of the Atmosphere.

Having thus detailed the opinions of ancient and modern writers on the composition of the atmosphere, we shall now proceed to point out briefly the variation it exhibits at different elevations,

or under other circumstances, and which affects its *weight,* its *pressure,* or *elasticity,* and its *temperature.*

1. *Weight and Pressure, or Elasticity of the Atmosphere; forming the Principle of Barometers, and the Ascent of Balloons.*

ELASTIC fluids are distinguished from liquids by the absence of all cohesive force, or by their immediate tendency to expand when they are at liberty. Such are atmospheric air, steam, and gases of various kinds; and the consideration of these fluids, in the state of rest, constitutes the doctrine of pneumatostatics, or of the equilibrium of elastic fluids.

That the air is a material substance, capable of resisting pressure, is easily shown, by inverting an empty jar in water; and by the operation of transferring airs and gases from vessel to vessel, in the pneumatic apparatus used by chemists. The tendency of the air to expand is shown by the experiment in which a flaccid bladder becomes distended, and shrivelled fruit recovers its full size, as soon as the external pressure is removed from it, by the operation of the air pump: and the magnitude of this expansive force is more distinctly seen, when a portion of air is inclosed in a glass vessel, together with some mercury, in which the mouth of a tube is immersed, while the other end is open, and without the vessel; so that when the whole apparatus is inclosed in a very long jar, and the air of the jar is exhausted, the column of mercury becomes the measure of the expansive force of the air.

If the diameter of the tube, in an apparatus of this kind, were very small in comparison with the bulk of the air confined, the column of mercury would be raised, in the ordinary circumstances of the atmosphere, to the height of nearly 30 inches. But supposing the magnitude of the tube such, that the portion of air must expand to twice its natural bulk, before the mercury acquired a height sufficient to counterpoise it, this height would be 15 inches only. For it appears to be a general law of all elastic fluids, that their pressure on any given surface is diminished exactly in the same proportion as their bulk is increased. If, therefore, the column of mercury in the vacuum of the air pump were 60 inches high, the air would be reduced to half its natural bulk; and for the same reason, the pressure of a column of 30 inches of mercury

in the open air will reduce any portion of air to half its bulk, since the natural pressure of the atmosphere, which is equal to that of about 30 inches of mercury, is doubled by the addition of an equal pressure. In the same manner the density of the air in a diving bell is doubled at the depth of 34 feet below the surface of the water, and tripled at the depth of 68 feet. This law was discovered by Dr. Hooke; he found, however, that when a very great pressure had been applied, so that the density became many times greater than in the natural state, the elasticity appeared to be somewhat less increased than the density; but this exception to the general law has not been confirmed by later and more accurate experiments.

Not only the common air of the atmosphere, and other permanently elastic gases, but also steams and vapours of all kinds, appear to be equally subject to this universal law: they must, however, be examined at temperatures sufficient to preserve them in a state of elasticity; for example, if we wished to determine the force of steam twice as dense as that which is usually produced, we should be obliged to employ a heat 30 or 40 degrees above that of boiling water: we should then find that steam of such a density as to support, when confined in a dry vessel, the pressure of a column of 30 inches of mercury, would be reduced to half its bulk by the pressure of a column of 60 inches. But if we increased the pressure much beyond this, the steam would be converted into water, and the experiment would be at an end.

That the air which surrounds us is subjected to the power of gravitation, and possesses weight, may be shown by weighing a vessel which has been exhausted by means of the air-pump, and then allowing the air to enter, and weighing it a second time. In this manner we may ascertain the specific gravity of the air, even if the exhaustion is only partial, provided that we know the proportion of the air left in the vessel to that which it originally contained. The pressure derived from the weight of the air is also the cause of the ascent of hydrogen gas, or of another portion of air which is rarefied by heat, and carries with it the marks of a fire; and the effect is made more conspicuous, when either the hydrogen gas, or the heated air, is confined in a balloon. The diminution of the apparent weight of a body, by means of the pressure of the surrounding air, is also shown by the destruction of the equilibrium

between two bodies of different densities, upon their removal from the open air into the vacuum of an air-pump. For this purpose, a light hollow bulb of glass may be exactly counterpoised in the air by a much smaller weight of brass, with an index, which shows, on a graduated scale, the degree in which the large ball is made to preponderate in the receiver of the air pump, by the rarefaction of the air, lessening the buoyant power which helps to support its weight.

From this combination of weight and elasticity in the atmosphere, it follows, that its upper parts must be much more rare than those which are nearer to the earth, since the density is every where proportional to the whole of the superincumbent weight. The weight of a column of air one foot in height is one twenty-eight thousandth of the pressure; consequently that pressure is increased one twenty-eight thousandth by the addition of the weight of one foot, and the next foot will be denser in the same proportion, since the density is always proportionate to the pressure; the pressure thus increased will therefore still be equal to twenty-eight thousand times the weight of the next foot. The same reasoning may be continued without limit, and it may be shown, that while we suppose the height to vary by any uniform steps, as by distances of a foot or a mile, the pressures and densities will increase in continual proportion; thus, at the height of about 3000 fathoms, the density will be about half as great as at the earth's surface; at the height of 6000, one-fourth; at 9000, one-eighth as great. Hence it is inferred that the height in fathoms may be readily found from the logarithm of the number expressing the density of the air: for the logarithm of the number 2, multiplied by 10,000, is 3010, the logarithms of numbers always increasing in continual proportion, when the numbers are taken larger and larger by equal steps. Hence we obtain an easy method of determining the heights of mountains with tolerable accuracy: for if a bottle of air were closely stopped on the summit of a mountain, and, being brought in this state into the plain below, its mouth were inserted into a vessel of water or of mercury, a certain portion of the liquid would enter the bottle; this being weighed, if it were found to be one-half of the quantity that the whole bottle would contain, it might be concluded that the air on the mountain possessed only half of the natural density, and that its height was 3000 fathoms. It ap-

pears also, from this statement, that the height of a column of equal density with any part of the atmosphere, equivalent to the pressure to which that part is subjected, is every where equal to about 28,000 feet.

Many corrections are, however, necessary for ascertaining the heights of mountains, with all the precision that the nature of this kind of measurement admits; and they involve several determinations, which require a previous knowledge of the effects of heat, and of the nature of the ascent of vapours.

We may easily ascertain, on the same principles, the height to which a balloon will ascend, if we are acquainted with its bulk and with its weight: thus, supposing its weight 500 pounds, and its bulk such as to enable it to raise 300 pounds more, its specific gravity must be five-eighths as great as that of the air, and it will continue to rise until it reaches the height, at which the air is of the same density: but the logarithm of eight-fifths, multiplied by 10,000, is 2040; and this is the number of fathoms contained in the height, which will, therefore, be a little more than two miles and a quarter. It may be found, by pursuing the calculation, that at the distance of the earth's semi-diameter, or nearly 4000 miles, above its surface, the air, if it existed, would become so rare, that a cubic inch would occupy a space equal to the sphere of Saturn's orbit: and on the other hand, if there were a mine about 42 miles deep, the air would become as dense as quicksilver at the bottom of it.

It appears, therefore, that all bodies existing on or near the earth's surface, may be considered as subjected to the pressure of a column of air, 28,000 feet high, supposing its density every where equal to that which it possesses at the earth's surface, and which is usually such, that 100 wine gallons weigh a pound avoirdupois, creating a pressure equal to that of 30 inches of mercury, or 34 feet of water, and which amounts to $14\frac{3}{4}$ pounds for each square inch. This pressure acts in all directions on every substance which is exposed to it: but being counterbalanced by the natural elasticity of these substances, it produces in common no apparent effects; when, however, by means of the air-pump, or otherwise, the pressure of the air is removed from one side of a body, while it continues to act on the other, its operation becomes extremely evident. Thus, when two hollow hemispheres, in contact with

each other, are exhausted of air, they are made to cohere with great force; they are named Magdeburg hemispheres, because Otto von Guerike, of Magdeburg, constructed two such hemispheres, of sufficient magnitude to withstand the draught of the Emperor's six coach-horses, pulling with all their force to separate them. By a similar pressure, a thin square bottle may be crushed when it is sufficiently exhausted, and a bladder may be torn with a loud noise: and the hand being placed on the mouth of a vessel which is connected with the air-pump, it is fixed to it very forcibly, when the exhaustion is performed, by the pressure of the air on the back of the hand; the fluids also, which circulate in the blood-vessels of the hand, are forced towards its lower surface, and the effect which is called suction, is produced in a very striking manner. It is on the same principle that cupping-glasses are employed, a partial exhaustion being procured by means of the flame of tow, which heats the air, and expels a great part of it: so that the remainder, when it cools, is considerably rarefied.

It was Galileo that first explained the nature of suction from the effects of the pressure of the atmosphere; and his pupil Torricelli confirmed his doctrines by employing a column of mercury, of sufficient height to overcome the whole pressure of the atmosphere, and to produce a vacuum in the upper part of the tube or vessel containing it. In the operation of sucking up a fluid through a pipe, with the mouth or otherwise, the pressure of the air is but partially removed from the upper surface of the fluid, and it becomes capable of ascending to a height which is determined by the difference of the densities of the air within and without the cavity concerned: thus, an exhaustion of one-fourth of the air of the cavity would enable us to raise water to the height of $8\frac{1}{2}$ feet, and mercury to $7\frac{1}{2}$ inches, above the level of the reservoir from which it rises. We can draw up a much higher column of mercury by sucking with the muscles of the mouth only, than by inspiring with the chest, and the difference is much more marked than the difference in the forces with which we can blow; for, in sucking, the cavity of the mouth is very much contracted by the pressure of the external air, and the same force, exerted on a smaller surface, is capable of counteracting a much greater hydrostatic or pneumatic pressure.

When a tube of glass, about three feet long, closed at one end

and open at the other, is filled with mercury, and then immersed in a basin of the same fluid, the pressure of the atmosphere is wholly removed from the upper surface of the mercury in the tube, while it continues to act on the mercury in the basin, and by its means on the lower surface of the column in the tube. If such a tube be placed under the receiver of an air-pump, the mercury will subside in the tube, accordingly as the pressure of the atmosphere is diminished; and if the exhaustion be rendered very perfect, it will descend very nearly to the level of the open basin or reservoir. When the air is readmitted, the mercury usually rises, on the level of the sea, to the height of about 30 inches; but the air being lighter at some times than at others, the height varies between the limits of 27 and 31 inches. This well known instrument, from its use in measuring the weight of the air, is called a barometer. In the same manner a column of water from 30 to 35 feet in height may be sustained in the pipe of a pump; but if the pipe were longer than this, a vacuum would be produced in the upper part of it, and the pump would be incapable of acting.

In order to observe the height of the mercury in the barometer with greater convenience and accuracy, the scale has sometimes been amplified by various methods; either by bending the upper part of the tube into an oblique position, as in the diagonal barometer, or by making the lower part horizontal, and of much smaller diameter than the upper, or by making the whole tube straight, and narrow, and slightly conical, or by placing a float on the surface of the mercury in the reservoir, and causing an axis, which carries an index, to revolve by its motion. But a good simple barometer, about one-third of an inch in diameter, furnished with a vernier, is perhaps fully as accurate as any of these more complicated instruments. In order to exclude the air the more completely from the tube, the mercury must at least be shaken in it for a considerable time, the tube being held in an inverted position; and where great accuracy is required, the mercury must be boiled in the tube. The reservoir most commonly employed is a flat wooden box, with a bottom of leather; the cover, which is unscrewed at pleasure, being cemented to the tube. Sometimes a screw is made to act on the leather, by means of which the surface of the mercury is always brought to a certain level, indicated by a float, whatever portion of it may be contained in the tube; but the necessity of this ad-

justment may be easily avoided, by allowing the mercury to play freely between two horizontal surfaces of wood, of moderate extent, and at the distance of one-seventh of an inch: the height may then be always measured from the upper surface, without sensible error. But if the surface were closer than this, the mercury would stand too high in the tube.

The same method which is employed in determining the relation between the heights and densities of elastic fluids, may be extended to all bodies which are in any degree comprehensible, and of which the elasticity is subjected to laws similar to those which are discoverable in the air and other gases: and it is not improbable that these laws are generally applicable to all bodies in nature, as far as their texture will allow them to submit to the operation of pressure, without wholly losing their form. Water, for example, has been observed by Canton to be compressed one-twenty-two thousandth of its bulk by a force equal to that of the pressure of the atmosphere; consequently this force may be represented by that of a column of water 750 thousand feet in height; the density of the water at the bottom of a lake, or of the sea, will be increased by the pressure of the superincumbent fluid; and supposing the law of compressure to resemble that of air, it may be inferred that at the depth of 100 miles, its density would be doubled; and that at 200 it would be quadrupled. The same measures would also be applicable to the elasticity of mercury. But there is reason to suppose that they are in both cases a little too small.

[*Young's Nat. Phil.*

Temperature of the Atmosphere.

That the temperature of the air varies considerably, not only in the different climates and in different seasons, but even in the same place and in the same season, must be obvious to the most careless observer. This perpetual variation cannot be ascribed to the direct heat of the sun; for the rays of that luminary seem to produce no effect whatever upon air, though ever so much concentrated: but they warm the surface of the earth, which communicates its heat to the surrounding atmosphere. Hence it happens that the temperature of the air is highest in those places which are

so situated as to be most warmed by the sun's rays, and that it varies in every region with the season of the year. Hence, too, the reason why it diminishes according to the height of the air above the surface of the earth. That portion of the earth which lies at the equator is exposed to the most perpendicular rays of the sun. Of course it is hottest, and the heat of the earth diminishes gradually from the equator to the poles. The temperature of the air must follow the same order. The air, then, is hottest over the equator, and its temperature gradually diminishes from the equator to the poles, where it is coldest of all. It is hottest at the equator, and it becomes gradually colder according to its height above that surface. Let us examine the nature of these two diminishing progressions of temperature.

1. Though the temperature of the air is highest at the equator, and gradually sinks as it approaches the pole; yet as, in every place, the temperature of the air is constantly varying with the season of the year, we cannot form any precise notion of the progression without taking the temperature in every degree of latitude for every day of the year, and forming for each a mean temperature for the whole year; which is done by adding together the whole observations, and dividing by their number. The quotient gives the mean temperature for the year. The diminution from the pole to the equator takes place in arithmetical progression: or, to speak more properly, the annual temperature of all the latitudes are arithmetical means between the mean annual temperature of the equator and the pole. This was first discovered by Mr. Meyer; and by means of an equation which he founded on it, but rendered considerably plainer and simpler, Mr. Kirwan has calculated the mean annual temperature of every degree of latitude between the equator and the pole. And according to this calculation the mean temperature of the equator is 84°, and that of the pole 31°. To find the mean temperature for every other latitude, we have only to find 88 arithmetical means between 84 and 31. In this manner Mr. Kirwan calculated the following Table:

TABLE *of the Mean Annual Temperature of the Standard Situation in every Latitude.*

Lat.	Temper.	Lat.	Temper.	Lat.	Temper.	Lat.	Temper.
90	31·	68	38·4	46	56·4	24	75·4
89	31·04	67	39·1	45	57·5	23	75·9
88	31·10	66	39·7	44	58·4	22	76·5
87	31·14	65	40·4	43	59·4	21	77·2
86	31·2	64	41·2	42	60·3	20	77·8
85	31·4	63	41·9	41	61·2	19	78·3
84	31·5	62	42·7	40	62·	18	78·9
83	31·7	61	43·5	39	63·	17	79·4
82	32·	60	44·3	38	63·9	16	79·9
81	32·2	59	45·09	37	64·8	15	80·4
80	32·6	58	45·8	36	65·7	14	80·8
79	32·9	57	46·7	35	66·6	13	81·3
78	33·2	56	47·5	34	67·4	12	81·7
77	33·7	55	48·4	33	68·3	11	82·
76	34·1	54	49·2	32	69·1	10	82·3
75	34·5	53	50·2	31	69·9	9	82·7
74	35·	52	51·1	30	70·7	8	82·9
73	35·5	51	52·4	29	71·5	7	83·2
72	36·	50	52·9	28	72·3	6	83·4
71	36·6	49	53·8	27	72·8	5	83·6
70	37·2	48	54·7	26	73·8	0	84·
69	37·8	47	55·6	25	74·5		

This Table, however, only answers for the temperature of the atmosphere of the ocean. It was calculated for that part of the Atlantic Ocean which lies between the 80th degree of northern and the 45th of southern latitude, and extends westward as far as the Gulf-stream, and to within a few leagues of the coast of America: and for all that part of the Pacific Ocean reaching from lat. 45° north to lat. 40° south, from the 20th to the 275th degree of longitude east of London. This part of the ocean Mr. Kirwan calls the standard: the rest of the ocean is subject to anomalies which will be afterwards mentioned.

Mr. Kirwan has also calculated the mean monthly temperature of the standard ocean. The principles on which he went were these: The mean temperature of April seems to approach very nearly to the mean annual temperature; and as far as heat depends

on the action of the solar rays, the mean heat of every month is as the mean altitude of the sun, or rather as the sine of the sun's altitude. The mean heat of April, therefore, and the sine of the sun's altitude being given, the mean heat of May is found in this manner: As the sine of the sun's mean altitude in April is to the mean heat of April, so is the sine of the sun's mean altitude in May to the mean heat of May. In the same manner the mean heats of June, July, and August, are found; but the rule would give the temperature of the succeeding months too low, because it does not take in the heat derived from the earth, which possesses a degree of heat nearly equal to the mean annual temperature. The real temperature of these months therefore must be looked upon as an arithmetical mean between the astronomical and terrestrial heats.

Mr. Kirwan, however, after going through a tedious calculation founded upon this principle, found the results to agree so ill with observation, that he drew up an extensive table of the monthly mean temperature of the standard from latitude 80° to lat. 10°, from which it appears that January is the coldest month in every latitude, and that July is the warmest month in all latitudes above 48°. In lower latitudes August is generally warmest. The difference between the hottest and coldest months increases in proportion to the distance from the equator. Every habitable latitude enjoys a mean heat of 60° degrees for at least two months; this heat seems necessary for the production of corn. Within ten degrees of the poles, the temperatures differs very little, neither do they differ much within ten degrees of the equator; the temperature of different years differ very little near the equator, but they differ more and more as the latitudes approach the poles.

2. That the temperature of the atmosphere gradually diminishes according to its height above the level of the sea, is well known. Thus the late Dr. Hutton of Edinburgh found that a thermometer kept on the top of Arthur's Seat, usually stood three degrees lower than a thermometer kept at the bottom of it. Hence, then, a height of 800 feet occasioned 3° of diminution of temperature. On the summit of Pinchinca the thermometer stood at 30°, as observed by Bouguer, while at the level of the sea in the same latitude it stood at 84°. Here a height of 15,564 feet occasioned a diminution of temperature amounting to 54°. But though there can be no doubt

of the gradual diminution of temperature, according to the height, it is by no means easy to determine the rate of diminution. Euler supposes it to be in a harmonic progression; but this opinion is contradicted by observations. Saussure supposes, that in temperate climates the diminution of temperature amounts to 1° for every 287 feet of elevation. But Mr. Kirwan has shown that no such rule holds, and that the rate of diminution varies with the temperature at the surface of the earth. We are indebted to this philosopher for a very ingenious method of determining the rate of diminution in every particular case, supposing the temperature at the surface of the earth known*.

Since the temperature of the atmosphere is constantly diminishing as we ascend above the level of the sea, it is obvious, that at a certain height we arrive at the region of perpetual congelation. This region varies in height according to the latitude of the place; it is highest at the equator, and descends gradually nearer the earth as we approach the poles. It varies also according to the season, being highest in summer and lowest in winter. M. Bouguer found the cold on the top of Pinchinca, one of the Andes, to extend from seven to nine degrees below the freezing point every morning immediately before sun-rise. He concluded, therefore, that the mean height of the *term of congelation* (the place where it freezes during some part of the day all the year round) between the tropics was 15·577 feet above the level of the sea; but in lat. 28° he placed it in summer at the height of 13,440 feet. Now, if we take the difference between the temperature of the equator and the freezing point, it is evident that it will bear the same proportion to the term of congelation at the equator, that the difference between the mean temperature of any other degree of latitude and the freezing point bears to the term of congelation in that latitude. Thus the mean heat of the equator being 84°, the difference between it and 32 is 52; the mean heat of latitude 28° is 72·3°, the difference between which and 32 is 40·3: Then 52 : 15577 :: 40·3 : 12072. In this manner Mr. Kirwan calculated the following Table:

* Irish Trans. viii. 356.

Lat.	Mean height of the Term of Congelation. Feet.
0	15577
5	15457
10	15067
15	14498
20	13719
25	13030
30	11592
35	10664
40	9016
45	7658
50	6260
55	4912
60	3684
65	2516
70	1557
75	748
80	120

Beyond this height, which has been called the lower term of congelation, and which must vary with the season and other circumstances, Mr. Bouguer has distinguished another, which he called the *upper* term of congelation; that is, the point above which no visible vapour ascends. Mr. Kirwan considers this line as much less liable to vary during the summer months than the lower term of congelation, and therefore has made choice of it to determine the rate of the diminution of heat, as we ascend in the atmosphere. Bouguer determined the height of this term in a single case, and Kirwan has calculated the following Table of its height for every degree of latitude in the northern hemisphere.

Table of the Height of the Upper Line of Congelation in the different Latitudes of the Northern Hemisphere.

N. Lat.	Feet.	N. Lat.	Feet.	N. Lat.	Feet.	N. Lat.	Feet.
0°	28000	26°	22906	48°	12245	70	4413
5	27784	27	22389	49	11750	71	4354
6	27644	28	21872	50	11253	72	4295
7	27504	29	21355	51	10124	73	4236
8	27364	30	20838	52	8965	74	4177
9	27224	31	20492	53	7806	75	4199
10	27084	32	20146	54	6647	76	4067
11	26880	33	19800	55	5617	77	4015
12	26676	34	19454	56	5533	78	3963
13	26472	35	19169	57	5439	79	3911
14	26268	36	18577	58	5345	80	3861
15	26061	37	17985	59	5251	81	3815
16	25781	38	17393	60	5148	82	3769
17	25501	39	16801	61	5068	83	3723
18	25221	40	16207	62	4989	84	3677
19	24941	41	15712	63	4910	85	3631
20	24661	42	15217	64	4831	86	3592
21	24404	43	14722	65	4752	87	3553
22	24147	44	14227	66	4684	88	3514
23	23890	45	13730	67	4616	89	3475
24	23633	46	13235	68	4548	90	3432
25	23423	47	12740	69	4480		

[*Thomson's Chemistry.*

From this method of estimating the diminution of temperature, which agrees remarkably well with observation, we see that the heat diminishes in an arithmetical progression. Hence it follows, that the heat of the air at a distance from the earth, is not owing to the ascent of hot strata of air from the surface of the earth, but to the conducting power of the air.

3. This rule, however, applies only to the temperature of the air during the summer months of the year. In winter the upper strata of the atmosphere are often warmer than the lower. Thus on the 31st of January 1776, the thermometer on the summit of Arthur's Seat stood six degrees higher than a thermometer at Hawkhill, which is 684 feet lower*. Mr. Kirwan considers this

* Roy. Phil. Trans. 1777, p. 777.

superior heat, almost uniformly observed during winter, as owing to a current of warm air from the equator, which rolls towards the north pole during our winter *.

4. Such, then, in general, is the method of finding the mean annual temperature over the globe. There are, however, several exceptions to these general rules, which come now to be mentioned.

That part of the Pacific Ocean which lies between north lat. 52° and 66°, is no broader at its northern extremity than 42 miles, and at its southern extremity than 1300 miles: it is reasonable to suppose, therefore, that its temperature will be considerably influenced by the surrounding land, which consists of ranges of mountains covered a great part of the year with snow; and there are besides a great many high, and consequently cold, islands scattered through it. For these reasons, Mr. Kirwan concludes, that its temperature is at least four or five degrees below the standard. But we are not yet furnished with a sufficient number of observations to determine this with accuracy.

It is the general opinion that the southern hemisphere, beyond the 40th degree of latitude, is considerably colder than the corresponding parts of the northern hemisphere. Mr. Kirwan has shown that this holds with respect to the summer of the southern hemisphere, but that the winter in the same latitudes is milder than in the northern hemisphere †.

Small seas surrounded with land, at least in temperate and cold climates, are generally warmer in summer and colder in winter than the standard ocean, because they are a good deal influenced by the temperature of the land. The Gulph of Bothnia, for instance, is for the most part frozen in winter; but in summer it is sometimes heated to 70°, a degree of heat never to be found in the opposite waters of the Atlantic ‡. The German sea is above three degrees colder in winter, and five degrees warmer in summer than the Atlantic §. The Mediterranean sea is, for the greater part of its extent, warmer both in summer and winter than the Atlantic, which therefore flows into the former. The Black Sea is colder than the Mediterranean, and flows into it ||.

The eastern parts of North America are much colder than the opposite coast of Europe, and fall short of the *standard* by about

* Irish Trans. viii. p. 375. † Irish Trans. viii. p. 417. ‡ Mem. Stock. 1776.
§ Kirwan's Temperature of Lat. p. 53. || Ibid.

10° or 12°, as appears from American Meteorological Tables*. The causes of this remarkable difference are many. The highest part of North America lies between the 40th and 50th degree of north latitude, and the 100th and 110th degree of longitude west from London; for there the greatest rivers originate. The very height, therefore, makes this spot colder than it otherwise would be. It is covered with immense forests, and abounds with large swamps and morasses, which render it incapable of receiving any great degree of heat; so that the rigour of winter is much less tempered by the heat of the earth than in the old continent. To the east lie a number of very large lakes; and farther north, Hudson's Bay; about 50 miles on the south of which there is a range of mountains, which prevent its receiving any heat from that quarter. This bay is bounded on the east by the mountainous country of Labrador and by a number of islands. Hence the coldness of the north-west winds and the lowness of the temperature. But as the cultivated parts of North America are now much warmer than formerly, there is reason to expect that the climate will become still milder when the country is better cleared of woods, though perhaps it will never equal the temperature of the old continent.

Islands are warmer than continents in the same degree of latitude; and countries lying to the windward of extensive mountains or forests are warmer than those lying to the leeward. Stones or sand have a less capacity for heat than earth has, which is always

* For the following statement of the extremes of heat and cold at Montreal and Three Rivers in Canada, I am indebted to an ingenious officer, who kept a register for eight years, from the year 1776 to 1784 inclusive.

"In the warmest summer the thermometer was not observed to rise higher than 94°, though it has been said to have risen so high as 96° and even 98° at Quebec; but where these observations were made, the thermometer was generally from 80° to 84° in the warmest summers, and the average of the ordinary summers was about 70°.

"In the severe frosts the thermometer sunk to 45° below 0. This happened three times within this period, viz. on the 23d and 25th February, 1782, and on the 10th February, 1784.

"In the ordinary winters, at Three Rivers, the mercury stood at from 10° to 25° below 0, and in the severe winters from 25° to 35° below 0.

"The summer observations were taken at about nine o'clock in the morning, and three in the afternoon. The winter, before sun-rise, and about nine, and sometimes ten o'clock at night.

somewhat moist; they heat or cool, therefore, more rapidly, and to a greater degree. Hence the violent heat of Arabia and Africa, and the intense cold of Terra del Fuego. Living vegetables alter their temperature very slowly, but their evaporation is great; and if they be tall and close, as in forests, they exclude the sun's rays from the earth, and shelter the winter snow from the wind and the sun. Woody countries, therefore, are much colder than those which are cultivated.

[*Thomson's Chemistry.*

The atmosphere is also liable to elevations and depressions analogous to those of the sea, and perhaps these changes may have some little effect on the winds and on the weather; but their influence must be very inconsiderable, since the addition of two or three feet to the height of the atmosphere at any part can scarcely be expected to be perceptible. The height of an aerial tide must be nearly the same with the observed height of the principal tides of the sea: and the variation of atmospherical pressure, which is measured between the difference of the actual form and the spheroid of equilibrium, must be equivalent to the weight of a column of about ten feet of air, or only $\frac{1}{100}$ of an inch of mercury. A periodical variation five times as great as this, has, indeed, been observed near the equator, where the state of the atmosphere is the least liable to accidental disturbances: but this change cannot in any degree be referred to the effect of the moon's action, since it happens always about the same hour of the day or night. The atmosphere is also affected by a general current from east to west, like that of the sea, and there is reason, from astronomical observations, to suppose that a similar circumstance happens in the atmosphere of Jupiter, on account of the actions of his satellites, which must be considerably more powerful than that of the moon.

[*Young's Nat. Phil.*

CHAP. XXXV.

ZONES AND CLIMATES.

Zones and Climates are artificial divisions of the earth's surface for the purpose of defining its temperature in particular parts; and they have hence an intimate connection with the temperature of the atmosphere, upon which indeed they are mainly though not altogether dependant.

Geographers have divided the surface of the globe into sixty climates, of which thirty are northward of the equator, and thirty southward; by these climates the length of the day, from sun-rising to sun-setting, is shewn, in its increase and decrease proceeding from the equator to the poles; from the equator to the arctic, or northern polar circle, twenty-four climates are traced out, and through each a difference of half an hour arises in the length of the day and night; and in like manner from the equator to the antarctic, or southern polar circle. The six climates which lie between the polar circles and the poles, both the northern and the southern, differ from each other by one entire month progressively.

As climates describe the length of days, so zones describe the degree of heat prevailing on different parts of the earth. Both ancient and modern geographers agree in dividing the earth into five zones in number and three in quality, namely, the torrid, the temperate north and south, and the frigid both north and south. The torrid zone extends from the equator to the tropic of cancer northward, and to the tropic of capricorn southward, twenty-three degrees and an half each (very nearly), making forty-seven degrees in all. The two temperate zones extend themselves from the two tropics to the polar circles on each side the equator, being forty-three degrees each, and eighty-six degrees in the whole.—The two frigid zones embrace the regions from the polar circles to the poles, extending, in each direction, over twenty-three and an

half degrees, in the whole forty degrees. Thus northward or southward,

Torrid zone...............	$23\frac{1}{2}$
Temperate	43
Frigid	$23\frac{1}{2}$
In the whole...............	90 degrees,

which is the distance from the equator to either pole; but considering the northern and southern regions in one account, the general division of the globe into zones will stand thus:

The torrid zones	47 degrees.
The temperate	86
The frigid...............	47
	180 degrees,

the extent of the earth from north to south, which geographers have divided into two hemispheres, viz. the northern and southern.

The ancients, having very imperfect knowledge of the globe, considered the two temperate zones as the only habitable parts of the earth, conceiving the heat of the torrid, and the cold of the frigid zones to be equally insupportable. This opinion is now well known to be erroneous; mankind having been ascertained to exist within the arctic circle; and some species of quadrupeds and birds even as high up as eighty degrees; while the attempts made by Captain Cook to penetrate within the antarctic circle, when he proceeded something beyond the seventy-first degree, proves that, although there is no known land lying much more southward than the sixtieth degree of south latitude, yet birds of curious kinds inhabit the expanse of ice, which, in every direction, stops all advance toward the south-pole. At the same time that the discovery of the West Indies and of the American continent, had clearly established that the population of mankind either is or may be rendered equal within the region of the torrid zone to that of the best inhabited countries of Europe.

The climates of different parts of the earth's surface are unquestionably owing in a great measure to their position with respect to the sun. At the equator, where the sun is always nearly vertical, any given part of the surface receives a much great quantity of light and heat, than an equal portion near the poles; and it is

also still more affected by the sun's vertical rays, because their passage through the atmosphere is shorter than that of the oblique rays. As far as the sun's mean altitude only is concerned, it appears from Simson's calculations, that the heat received at the equator in the whole year, is nearly twice and a half as great as at the poles; this proportion being nearly the same as that of the meridan heat of a vertical sun, to the heat derived, at the altitude $23\frac{1}{2}°$, in the middle of the long annual day at the poles. But the difference is rendered still greater, by the effect of the atmosphere, which interrupts a greater portion of the heat at the poles than elsewhere. Bouguer has calculated, upon the supposition of the similarity of the affections of heat and light, that in latitude 45°, 80 parts out of 100 are transmitted at noon in July, and 55 only in December. The heat intercepted by the atmosphere is perhaps not wholly, but very nearly, lost with respect to the climate of the neighbouring places. It is obvious that, at any individual place, the climate in summer must approach in some degree to the equatorial climate, the sun's altitude being greater, and in winter to the climate of the polar regions.

While the earth is becoming warmer at any particular spot, the heat thrown off by radiation into the atmosphere, and thence into the empty space beyond it, together with that which is transmitted to the intetnal parts of the earth, must be less than the heat received from the sun; and when the earth is growing colder, more heat must pass off than is received: but whenever the heat of the surface is stationary, neither increasing nor diminishing, as at the times of the greatest and least heat, it is obvious that the heat received from the sun must be precisely equal to the heat which is thrown off. Now this quantity may be estimated by the degree of refrigeration in the night; and hence Mr. Prévost has very ingeniously deduced the proportion of the sun's heat arriving at the surface of the earth in the latitude of Geneva, in July, and in December; which he finds to be as 7 or 8 to 1; and this result agrees very well with a calculation deduced from the length of the day, the sun's altitude, and the interception of his rays by the atmosphere.

In London the temperature generally varies, in the course of the day and night, somewhat more than 5°, and less than 20°. In January, the mean diurnal variation of temperature is 6°, in

July 10°, and in September, 18°. Hence, says Mr. Kirwan, we may understand the reason of the great frequency of colds in spring and in autumn.

Some philosophers have supposed the earth to become progressively warmer in the course of ages, while others have imagined that its heat is exhausted. Both these opinions appear in general improbable. The greater heat the earth receives by day, the more it throws off, both by day and by night; so that in the course of a few ages the heat must probably have attained its maximum. Local changes may indeed arise from local circumstances; thus, the climate of America is said to have become considerably warmer, since a large part of its surface has been cleared from its dense forests by human labour; and to judge from the descriptions of the ancients, it appears that even in Europe the winters were formerly much colder than they are at present. If, however, Dr. Herschel's opinion of the variation of the heat of the sun be confirmed, it will introduce a great uncertainty into all theories upon the subject: since in these calculatious the original heat of the sun has always been supposed unalterable.

The sea is less heated than the land, partly because a greater quantity of water evaporates from it, and partly because the sun's rays penetrate to a considerable depth, and have less effect on the surface, while the water is also mixed, by the agitation of its waves and currents, with the colder water below. It is also more slowly cooled than the land, since, when the temperature of the superficial particles is depressed, they become heavier, and sink to the bottom. For similar reasons, the sea is colder than the land in hot climates, by day, and warmer in cold climates, by night. These circumstances, however, nearly balance each other, so that the mean temperatures of both are equal, that of the sea being only less variable. Although the process of evaporation must cool the sea, yet when the vapours are condensed without reaching the land, their condensation must compensate for this effect by an equal extrication of heat.

There is another cause which perhaps contributes in some degree, in temperate climates, to the production of cold; that is, the alternation of freezing and thawing. Mr. Prévost observes that congelation takes place much more suddenly than the opposite process of liquefaction; and that of course the same quantity

of heat must be more rapidly extricated in freezing than is absorbed in thawing; that the heat, thus extricated, being disposed to fly off in all directions, and little of it being retained by the neighbouring bodies, more heat is lost than is gained by the alternation: so that where ice has once been formed, its production is in this manner redoubled. This circumstance must occur wherever it freezes, that is, on shore, in latitudes above 35°; and it appears that from about 30° to the pole, the land is somewhat colder than the sea, and the more as it is further distant from it; and nearer the equator the land is warmer than the sea: but the process of congelation cannot by any means be the principal cause of the difference, and it is probable that the different capacity of earth and water for heat is materially concerned in it.

Since the atmosphere is very little heated by the passage of the sun's rays through it, it is naturally colder than the earth's surface; and for this reason, the most elevated tracts of land, which are the most prominent, and the most exposed to the effects of the atmosphere, are always colder than situations nearer the level of the sea. The northern hemisphere is somewhat warmer than the southern, perhaps because of the greater proportion of land that it contains, and also in some measure on account of the greater length of its summer than that of the southern; for although, as it was long ago observed by Simpson, the different distance of the sun compensates precisely for the different velocity of the earth in its orbit, with respect to the whole quantity of heat received on either side of the equinoctial points, yet Mr. Prévost has shown, that in all probability the same quantity of heat must produce a greater effect when it is more slowly applied; because the portion lost by radiation from the heated body is greater, as the temperature is higher. Since, therefore, on account of the eccentricity of the earth's orbit, the north pole is turned towards the sun seven or eight days longer than the south pole, the northern winters must be milder than the southern: yet the southern summers, though shorter, ought to be somewhat warmer than the northern: but in fact they are colder, partly perhaps from the much greater proportion of sea, which in some degree equalises the temperature, and partly for other reasons. The comparative intensity of the southern summer and winter is not exactly known;

but in the island of New Georgia the summer is said to be extremely cold.

The northern ice extends about 9° from the pole: the southern 18° or 20°; in some parts even 30°; and floating ice has occasionally been found in both hemispheres as far as 40° from the poles, and sometimes, as it has been said, even in latitude 41° or 42°. Between 54° and 60° south latitude, the snow lies on the ground, at the sea side, throughout the summer. The line of perpetual congelation is three miles above the surface at the equator, where the mean heat is 84°; at Teneriffe, in latitude 28°, two miles; in the latitude of London, a little more than a mile; and in latitude 80° north, only 1200 feet. At the pole, according to the analogy deduced by Mr. Kirwan, from a comparison of various observations, the mean temperature should be 31°. In London the mean temperature is 50°; at Rome and at Montpelier, a little more than 60°; in the Island of Madeira, 70°; and in Jamaica, 80°.

There are frequently some local causes of heat and cold which are independent of the sun's immediate action. Thus, it has been observed, that when the weather has been clear, and a cloud passes over the place of observation, the thermometer frequently rises a degree or two almost instantaneously. This has been partly explained by considering the cloud as a vesture, preventing the escape of the heat which is always radiating from the earth, and reflecting it back to the surface: the cloud may also have been lately condensed, and may itself be of a higher temperature than the earth. Mr. Six has observed that in clear weather, the air is usually some degrees colder at night, and warmer by day, close to the ground, than a few feet above it; but that in cloudy weather there is less difference: and it is possible that this circumstance may be derived from the difference of the quantity of evaporation from the earth's surface, which occasions a different degree of cold in different states of the atmosphere.

An idea has frequently been started, that the temperature of several, perhaps of all climates, has varied at different epochs, and is in truth perpetually varying; in some instances for the better, and in others apparently for the worse. And the more or less active cultivation of the soil, the clearing and draining of the ground, or the suffering it to lie barren and unproductive, co-

vered with woods and morasses, are the causes which have chiefly been adverted to for the purpose of explaining these phænomena.

After all, however, the assertion, as relating to a general fact, requires to be more attentively examined than it appears to have been; and, admitting its truth, the cultivation or neglect of the soil does not seem in every instance to constitute the actual cause of this difference in the temperature.

In America, observes an intelligent Irish writer in the Philosophical Transactions*, at least as far as the modern plantations are extended, an extraordinary alteration has been perceived in the temperature of the country since the Europeans began to settle there. This change, continues he, is generally attributed to the cutting down of vast woods, with the clearing and cultivating of the country. But that Ireland should also considerably alter without any such manifest cause, either invalidates that reason, or else evinces that quite different causes may produce the same effect. For if it be true, as some compute, that this kingdom was better inhabited and cultivated before the late civil wars, than at present †, it should, according to the reasons alledged for the change of temperature in America, be rather grown more intemperate, viz. for want of cultivation: but the contrary is observable here, and almost every one begins to take notice, that this country becomes every year more and more temperate. Formerly it was not unusual to have frost and deep snows of a fortnight or three weeks continuance; and that twice or thrice, sometimes oftener, in a winter; nay we have had great rivers and lakes frozen all over; whereas of late, especially these two or three years last past, we have had scarcely any frost or snow at all. Neither can I impute this extraordinary alteration to any fortuitous concourse of ordinary circumstances requisite to the production of fair weather; because it is manifest, that it has proceeded gradually, every year becoming more temperate than the preceding. Though it be observed that frosty and snowy winters make early springs, and for as little as we have had of either this winter, yet there has not within the memory of any now living happened a forwarder spring in Ireland; since this island could produce some store of ripe cherries in the midst of April. The wind keeps for the most part here between the north-west and the south, seldom at east,

* Vol. xi. year 1676.

† The paper here referred to bears the date of 1676. EDIT.

and yet less frequent at north or north-east, insomuch that many here do not scruple to affirm, that for at least $\frac{3}{4}$ of the year the wind is westerly; and we have sometimes known passengers wait at Chester and Holyhead no less than three months for a fair wind to come hither.

The Honourable Daines Barrington is well known to have entertained a similar opinion, and to have carried it to a much greater extent. He communicated it chiefly in an article in a much later volume of the valuable journal we have just referred to*; and its substance we shall lay before our readers in the admirable summary of it which is given in the twelfth volume of the recent abridgment of this work.

Mr. Barrington, observes the Editor, had long entertained a notion that the seasons are become much milder in the northern latitudes than they were 16 or 17 centuries past; and from this it has happened, that many passages in the classic writers descriptive of the severity of the climates, had struck him more perhaps than they would a common reader.

If this same question should be agitated 2000 years hence, it might receive an absolute demonstration; as a journal of the changes in a well-constructed thermometer would show the temperature which prevailed in any particular place, during the present century. No such accuracy can be expected from any passages in the classical writers; but in order to state the alteration which may have happened in so long a course of years, the most proper method seems to be to compare their accounts with those of more modern travellers, who have equally wanted the assistance of a thermometer for their observations.

Mr. B. chiefly relies on many of Ovid's letters from Pontus (though he was not only a poet, but a writer of most glowing fancy and imagination,) in which he describes the effects of cold at Tomas, probably the modern Temisware, during his seven years residence there, and afterwards contrasts this description with that of later travellers. Ovid was born at Sulmo in Italy, about 90 Roman miles S. W. from the capital. He afterwards resided chiefly at Rome, and was there at the time he received the emperor's orders for his immediate banishment: Mr. B. therefore considers him as then leaving the 42d degree of northern latitude, the

* Phil. Trans. Vol. lvii. year 1768.

climate in which he was born, and continued to live. He was thence removed to Tomos, which Dr. Wells, in his maps of ancient geography, places only in the 44th degree of northern latitude: the change was therefore only of 2 degrees, and yet Ovid immediately describes it as the winter of Hudson's Bay, with the Euxine sea frozen over, with people and cattle walking on it; as well as other instances of extreme cold.

Besides the quotations from Ovid, Mr. B. gives several others from the ancients, as Virgil, Strabo, Pliny, &c. descriptive of the excessive cold of that latitude. He then contrasts these with the accounts of modern travellers in that country, who have not noticed any such severities of climate there.

Mr. B. now leaving Tomos, compares the accounts of the weather in Italy, with those of the present times: it being first premised, that the country was better cultivated in the Augustan age than it is now, which should consequently have made the temperature of the air more warm than it is now experienced to be. He begins with some passages from Virgil's Georgics. This most excellent husbandman is constantly advising precautions against snow and ice in the management of cattle; and he may be generally supposed to give these directions for the neighbourhood of Naples, or Mantua his native country, where he does not evidently from the context mean some other parts of Italy. Speaking afterwards of Calabria, the most southern part of Italy, he expresses himself, with regard to the rivers being frozen, as what was commonly to be expected. Pliny too in a chapter, *De natura cœli ad arbores*, and speaking of Italian trees, says, *Alioqui arborum frugumque communia sunt, nives diutinas sedere.* But perhaps the strongest proof of that very remarkable fact, the Italian rivers being constantly frozen over, is to be collected from a chapter in Ælian, which consists entirely of instructions how to catch eels while the water is covered with ice. Now, if we may believe the concurrent accounts of modern travellers, it would be almost as ridiculous to advise a method of catching fish in the rivers of Italy, which depended entirely on their commonly being frozen over, as it would be to give such directions to the inhabitants of Jamaica. Mr. B. cannot find that the precautions, which Virgil gives in his Georgics, against the damages which sheep and goats might receive from the snow and frost, are now necessary; and both these animals are

known to stand the severest winters of the Highlands of Scotland, conceived to be in Virgil's time almost the ultima Thule. On the whole Mr. B. infers, that there appears to have been a general melioration of temperature in the air and the seasons, in many, perhaps most parts of the earth.

[*Phil. Trans.* 1768.

CHAP. XXXVI.

NATURE, PROPERTIES, AND VARIATIONS OF HEAT.

SECTION I.

Sources and Effects of Heat.

The sources of heat are various, but its effects uniform, whatever the cause that produces it; or rather, perhaps, the essence or material of which it consists is the same in every instance. The most powerful and extensive source of heat with which we are acquainted is the sun, from which perhaps this invisible matter (if matter at all) is emitted, in consequence of the chemical processes that continually take place at its surface. Friction is another powerful source of heat; percussion is a third; and there are a few others which have not yet been sufficiently traced out and explained.

The recent opinions upon this curious subject are given with so much perspicuity, and at the same time such convenient succinctness by Sir Humphry Davy, that through the remainder of this chapter we shall take leave to borrow his words.

When a body which occasions the sensation of heat on our organs, is brought into contact with another body which has no such effect, the result of their mutual action is, that the hot body contracts, and loses to a certain extent its power of communicating heat, and the other body expands, and in a degree acquires this power.

This law may be exemplified with respect to every form of pon-

derable matter. If a polished cylinder of tin, which accurately fits a ring, be heated so as to make water boil, it will no longer pass through the ring, and will be found enlarged in all its dimensions. If spirits of wine be heated in a glass vessel having a narrow tubulated neck, as it becomes capable of communicating the sensation of heat, it will be found to expand and to rise in the narrow neck; and if the body of the same vessel be filled with air, and it be inverted in water, its neck containing water, the air will rapidly expand, on the application of a heated body, and will cause the water to descend in the neck of the vessel.

2. Different solids and fluids expand very differently when heated by the same means.

Glass is less expansible than any of the metals; 100,000 parts raised from the degree of freezing to that of boiling water, expand so as to become 100,083 parts; 100,000 of platinum under similar circumstances expand so as to become 100,087; and equal parts of gold, antimony, cast iron, steel, iron, bismuth, copper, cast brass, silver, tin, lead zinc, and hammered zinc, expand in the following order: 100,094, 100,108, 100,111, 100,112, 100,126, 100,139, 100,170, 100,189, 100,238, 100,287, 100,296, 100,308. The expansive power of liquids in general is greater than that of solids; alcohol appears to be more expansible than oils, and oils in general more expansible than water. 100,000 parts of mercury of the same degree of heat as ice, become at the degree of heat at which water boils 101,835. All the elastic fluids, or the different species of air that have been examined, as has been demonstrated by Messrs. Dalton and Gay Lussac, expand alike when heated to the same degree; 100 parts of each at the freezing point of water becoming about 137,5 at the boiling point.

It is evident that the density of bodies must be diminished by expansion; and in the case of fluids and gases, the parts of which are mobile, many important phenomena depend upon this circumstance. If heat be applied to fluids or to gases, the heated parts change their places and rise; and the colder parts descend and occupy their places. Currents are constantly produced in the ocean and in great bodies of water, in consequence of this effect. The heated water rises to the surface in the tropical climates, and flows towards colder ones; thus the warmth of the Gulf-stream is felt a thousand miles from its source; and deep currents pass from the

colder to the warmer parts of the sea: and the general tendency of these changes is to equalize the temperature of the globe.

In the atmosphere, heated air is constantly rising, and colder air rushes in to supply its place; and this event is the principal cause of winds: the air that flows from the poles towards the equator, in consequence of the rotation of the earth, has less motion than the atmosphere into which it passes, and occasions an easterly current; the air passing from the equator towards the poles having more motion, occasions a westerly current; and by these changes, the different parts of the atmosphere are mixed together: cold is subdued by heat, moist air from the sea is mixed with dry air from the land, and the great mass of elastic fluid surrounding the globe, preserved in a state fitted for the purpose of vegetable and animal life.

3. There are very few exceptions to the law of the *expansion* of bodies, at the time they become capable of communicating the sensation of heat; and these exceptions seem entirely to depend upon some chemical change in the constitution of bodies, or on their crystalline arrangements. Thus clay contracts considerably in dimensions by a very intense heat, and on the measure of its contractions the pyrometer of Wedgwood is founded: but in this case the clay first gives off water, which was united to its parts, and afterwards these parts cohere together with more force, and from being in a state of loose aggregation, become strongly united. Water expands a little before it congeals, and expands considerably during its conversion into ice; but in this case it assumes the crystalline form; and its parts whilst they are arranging themselves to form regular solids, probably leave greater interstices than they occupied when at uniform distances in the fluid. Thus the same weight of matter will occupy much greater space when arranged in a certain number of octahedrons, than when arranged in a similar number of cubes, or hexagonal prisms. Certain saline solutions likewise that shoot into prismatic crystals, expand at the moment they become solid; and the case is the same with cast iron, bismuth, and antimony.

The expansion of water during its conversion into ice, is shewn by the circumstance of ice swimming upon water; and if water in a deep vessel be examined at the time ice is forming, it will be found a little warmer at the bottom than at the top; and these cir-

cumstances are of great importance in the œconomy of nature. Water congeals only at the surface, where it is liable to be acted upon by the sun, and by warm currents of air which tend to restore it to the fluid state; and when water approaches near the point of freezing, it begins to descend, so that no ice can form till the whole of the water has been cooled to the point where it possesses the greatest density; and in the deep parts of the sea and lakes, even in some of the northern latitudes, the duration of the long winter is insufficient to cool the water to the degree at which ice forms.

4. When equal quantities of the same matter differently heated are mixed together, as much as the one contracts, so much the other seems to expand. It is easy to prove this by shaking together 100 parts of mercury so hot as not to be touched without pain, and 100 parts in its common state, having previously measured the space they occupy; if the mixture is made in the tube that contained the hot mercury, there will be no sensible change of volume.

It is on the idea, that when heat or the power of repulsion is communicated from body to body, as much is gained by one body as is lost by the other, that thermometers have been framed, and the doctrines of temperature and capacity for heat founded.

5. The most common thermometer is a glass bulb, containing mercury, terminated by a glass tube, having a very narrow bore. The mercury is boiled to expel any air or moisture that might be attached to it; and at the moment it is in ebullition, the extremity of the tube being drawn to a fine point, is hermetically sealed by a spirit lamp. For the purpose of acquiring a scale, the bulb is first plunged into melting ice, and the place where the mercury stands is marked; the bulb is afterwards plunged into boiling water, and the same operation repeated. On Fahrenheit's scale, this space is divided into 180 equal parts, and similar parts are taken above and below for extending the scale, and the freezing point of water is placed at 32°, and the boiling point at 212°. In Fahrenheit's scale 1.8 degrees are equal to one degree of the centigrade thermometer, and 2.25 to one degree of Reaumur.

Other fluids besides mercury, such as alcohol, are sometimes used in thermometers, particularly for measuring low degrees when mercury freezes.

Air is employed in the differential thermometer, which consists of two bulbs filled with air, and connected by a capillary tube containing oil of vitriol: the heated body is brought in contact with one bulb, the air of which expands and drives the fluid towards the other bulb.

6. *Temperature* is the power bodies possess of communicating or receiving heat, or the energy of repulsion; and the temperature of a body is said to be high or low with respect to another, in proportion as it occasions an expansion or contraction of its parts; and the thermometer is the common measure of temperature.

7. When equal volumes of different bodies of different temperatures are suffered to remain in contact till they are possessed of the same temperature, it is found that this temperature is not a mean one, as it would be in the case of equal volumes of the same body. Thus, if a pint of quicksilver at 100°, be mixed with a pint of water at 50°, the resulting temperature is not 75°, but about 70°: the mercury has lost 30°, whereas the water has gained only 20°. In the common language of chemical philosophers this difference is said to depend upon the different *capacities* of bodies for heat, and the *capacity* of a body is said to be greater or less, in proportion as its temperature is less or more raised by the addition, or diminished by the subtraction of equal quantities of the power of repulsion, or heat. Thus mercury is said to have a much less capacity for heat than water; and taking the facts above stated as data, and comparing the weights of the two bodies, which are as 13·3 to 1, their capacities will be to each other as about 19 to 1.

Tables of the relative capacities of bodies are given in the works of different authors. In referring to the various bodies which are the subjects of chemistry, this property will be described amongst other properties. In general it appears that the substances most expansible by heat are those which have the greatest capacities; thus gases in general have greater capacities than fluids, and fluids than solids; but the extra ratio has not been yet determined.

8. Different bodies, it appears, have their temperatures differently raised by the addition, or diminished by the subtraction of equal quantities of heat, or the power of repulsion, and they are likewise affected by heat, or expanded with very different degrees of celerity. If slender cylinders of silver, of glass, and of charcoal, of equal length and size, be held in the central part of the

flame of a candle, the silver rapidly becomes heated throughout, and cannot be held in the hand; the heat is more slowly communicated through the glass, but the charcoal becomes red-hot at the one extremity long before any heat is felt at the other extremity. These differences are said to depend upon the different powers of these bodies *for conducting* heat; thus the silver is said to be a better conductor than the glass, and the glass than the charcoal. In general those bodies that are the densest, and that have the least capacity for heat, are the best conductors; thus the metals conduct better than any other solids; gases are worse conductors than fluids, and fluids than solids: but there are exceptions with respect to this correspondence between conducting powers and density, and a remarkable one, in the densest known body in nature, platina, which is perhaps the worst conductor amongst the metals.

Animal and vegetable substances, in general, are very bad conductors; thus the hair and wool of animals, and the feathers of birds, are admirably fitted to protect them from the cold, and they inclose and retain air, which, being a still worse conductor, enhances the effect. It was supposed, by Count Rumford, that the fluids and gases are perfect *nonconductors* of heat, and that their particles can be heated in no other way, except by coming in succession to the source of heat; but some very conclusive experiments seem to render this opinion untenable. In general, however, fluids and gases alter their places, from a change of specific gravity much more rapidly than they communicate or receive heat. This is illustrated by a very simple experiment: let an air thermometer be inverted in a vessel of water, so that the extremity of the bulb is barely beneath the surface: let a little ether be poured upon the water so as to form a stratum about $\frac{1}{8}$ of an inch above the thermometer, and let the ether be inflamed; however delicate the thermometer, the air in it will not soon expand; the ether boils violently, but a very long process of this kind is required to communicate any sensible heat to the water. Unless the particles of gases and fluids had been capable of communicating heat to a certain extent, the upper strata of liquids would be almost the only permanently heated parts; and heat would be constantly accumulating on the surface of extensive seas. Our lower atmosphere likewise would be intensely cold during the absence of the sun: but by the relations between the conducting power and the mobility of fluids

and gases; the changes of temperature of air and water are made progressive and equable, and adapted to a habitable globe. As heat is propagated very slowly through gaseous bodies, so they communicate it very slowly to other bodies, a circumstance that might be expected from the small quantity of matter they contain, when compared to other substances. The heat of metals at the temperature of 120° is scarcely supportable; water scalds at 150°; but air may be heated at 240° without being painful to our organs of sensation, and a temperature near this was experienced for some minutes, by Sir Joseph Banks, Sir Charles Blagden, and Dr. Fordyce, in a room artificially heated.

The power of abstracting heat in air is likewise comparatively very small; in the high northern latitudes a cold has been experienced without injury, in which mercury froze; and, if in this state of the atmosphere, metallic substances, of the same temperature, were touched, a sensation like that of burning was experienced, and the part blistered.

9. Heat, or the power of repulsion, may be considered as the *antagonist* power to the attraction of cohesion, the one tending to separate, the other to unite the parts of bodies; and the forms of bodies depend upon their respective agencies. In solids the attractive force predominates over the repulsive; in fluids, and in elastic fluids, they may be regarded as in different states of equilibrium; and in ethereal substances the repulsive must be considered as predominating over, and destroying the attractive force.

All the different substances in nature, under certain circumstances, are probably capable of assuming all these forms; thus solids, by a certain increase of temperature, become fluids, and fluids gases; and *vice versâ,* by a diminution of temperature gases become fluids, and fluids solids.

Instances of the fusion of solids by heat are too familar to require any particular notice: when water becomes steam by boiling, it is merely the conversion of a fluid into an elastic fluid; and a simple instance of this circumstance may be given in the ebullition of ether. Let a little ether be introduced into a small glass retort filled with water, and inverted in water; the ether will swim above the water, in the upper part of the retort; let a heated bar of metal be held near the part of the retort containing the ether; as the heat is communicated, globules will be seen to rise, and in a

very short time elastic fluid will be formed, in such quantities, as to expel the water from the vessel: on suffering the glass to cool, the elastic matter will be condensed, and will become again fluid.

If a globule of mercury be held in a spoon of platina, over the flame of a lamp, it will be vividly agitated, and will rapidly diminish. This is owing to its becoming elastic, and flying off in gas: and by a very low temperature, which may be artificially produced by mixing together very cold snow and a salt called muriate of lime, mercury may be congealed into the solid form.

Different bodies change their states at very different temperatures. Thus mercury, which is a solid at about 40° below Fahrenheit, boils at about 660°; sulphur, which becomes fluid at 218°, boils at 570°; ether boils at 98°. The temperatures at which the common metals become gaseous, are generally very high, and most of them incapable of being produced by common means. Iron, manganese, platina, and some other metals, which can scarcely be fused in the best furnaces, are readily melted by electricity; and by the Voltaic apparatus a degree of heat is attained, in which platina not only fuses with readiness, but seems even to evaporate.

With respect to the conversion of solids, fluids, or gases, into ethereal substances, the proofs are not of the same distinct nature as those belonging to their conversion into each other. When the temperature of a body is raised to a certain extent, it becomes luminous; and heated bodies not only affect other bodies by direct contact, but likewise exert an influence on them at a distance, which is ascribed to what is usually called radiant heat. One solution of this phenomenon is, that particles are thrown off from heated bodies with great velocity, which, by acting on our organs, produce the sensations of heat or light, and that their motion, communicated to the particles of other bodies, has the power of expanding them; thus if heat, or the force of repulsion, be so increased in an elastic fluid, as to overcome the force of cohesion and gravitation, these particles would move in right lines through free space; and we know of no other effects they could produce, than those of heat and light. It is perhaps in favour of this opinion, that all the different elastic fluids expand equally, when their temperatures are equally raised; and from observations made on the eclipses of Jupiter's satellites, and from other phenomena presented by the heavenly bodies, it appears that the motions of light are equable.

It may, however, be said, that the radiant matters emitted by bodies in ignition, are specific substances, and that common matter is not susceptible of assuming this form; or it may be contended, that the phenomena of radiation do, in fact, depend upon motions communicated to subtile matter every where existing in space.

9. The temperatures at which bodies change their states from fluids to solids, though in general definite, are influenced by a few circumstances, such as motion and pressure. Water, kept perfectly at rest, may sometimes be cooled to 22°, without congelation; but if at a temperature below 32° it be agitated, ice instantly forms. A saturated solution of Glauber's salt, introduced whilst warm into a bottle, from which the pressure of the atmosphere is excluded, remains liquid after cooling, but if the atmosphere be suffered to act upon it, it instantly crystallizes. The boiling point of fluids is still less fixed, than the point of fusion of solids, and is immediately dependent upon pressure. Thus ether will boil readily at the freezing point of water, in the exhausted receiver of an air-pump; and it appears from the researches of Professor Robinson, that in a vacuum all liquids boil about 145° lower than in the open air. Under pressure, liquids may be heated to a high degree; water in a Papin's digester, may have its temperature raised to 300°, but at the moment the pressure is removed, elastic matter is disengaged with great violence.

10. A peculiar distinction has been made by some authors between permanent elastic fluids, and elastic fluids which are condensible by pressure or cold; but these substances differ only in the degree of the point of vaporization; and steam at 500 degrees of Fahrenheit, there is every reason to believe, would be equally incondensible with air at a range of temperature such as we can command below our common temperatures: and some gases that are permanent under all common circumstances, as ammonia, are condensible by intense cold aided by pressure.

All bodies that boil at moderate temperatures, seem to evaporate, so as to produce a certain quantity of elastic matter in the common state of the atmosphere; and this quantity is greater in proportion as the temperature is high. According to Mr. Dalton, the force of vapour increases in geometrical progression to the temperature, but the ratio differs in different fluids. It is certain

that as the temperature approaches near the point of ebullition, in liquids, the strength of the vapour, *i. e.* the quantity that would rise in free space, rapidly increases.

In hot, dry weather, it is obvious that there must be much more vapour in the atmosphere than in cold wet weather; and the largest quantity exists in summer and in the tropical climates, when moisture is most needed for the purposes of life; and it appears to be the aqueous vapour in the atmosphere, which, when condensed by the mixture of cold with hot air, or by other agencies occasioning a change of its temperature, is the cause of dew, mists, rain, and ultimately of springs and rivers.

11. When solids are converted into fluids, or fluids into gases, there is always a loss of heat of temperature, and *vice versâ*, when gases are converted into fluids, or fluids into solids, there is an increase of heat of temperature, and in this case it is said that *latent heat* is absorbed or given out. Thus if equal weights of snow at 32° and of water at 172° be mixed together, the whole of the snow is melted, but the temperature of the mixture is found to be 32°, so that 140° degrees of heat are lost. Again, if water be heated in a Papin's digester to 300 degrees, and the valve be raised, a quantity of steam instantly rises, which has the temperature of 212°, and the temperature of the water in the digester is found to be the same, so that a great quantity of heat of temperature is lost in converting the water into steam.

If, when the air is at 20°, a quantity of water be exposed to it in a tall glass, the water gradually cools down to 22° without freezing, but if it be shaken, so as to be converted into ice, the temperature of the ice is found to be at 32°, so that the degree of heat is raised during the act of freezing.

If one part of steam or aqueous gas, at 212°, be mixed with six parts by weight of water at 62°, the whole of the steam will be condensed, and the temperature of the fluid will be about 212°, so that there is an immense increase of the heat of temperature, and 900° may be considered as taken from the steam, and as added to the water.

All the phenomena of these changes may be referred to a simple general law, of which Dr. Black was the discoverer, and which has been most ably illustrated by the researches of Wilke, Watt, Irvine, and Crawford, namely, " that whenever a body changes

its form, its relations to temperature are likewise changed, either increased or diminished;" and many important operations, both artificial and natural, depend upon this law. The knowledge of it, for instance, led Mr. Watt to make his great improvement of the steam-engine, by which the steam is condensed out of the cylinder in which its force is efficient, and fresh gaseous matter introduced without any chance of a loss of its elasticity.

One of the most perfect modes of heating large rooms, and of procuring a uniform temperature for the purposes of manufacture, is by the condensation of steam. By the cold produced in consequence of the evaporation of water in hot climates, congelation is effected; and in the nights in Bengal, when the temperature is not below fifty, by the exposure of water in earthenware pans upon moistened bamboos, thin cakes of ice are formed, which are heaped together and preserved under-ground by being kept in contact with bad conductors of heat. The cold produced by evaporation, is likewise the cause of the formation of ice in Mr. Leslie's elegant experiment, in which sulphuric acid is placed in a vessel upon the plate of an air-pump, and water in another vessel raised above it; the surfaces both of the acid and the water being considerable. When an exhaustion is made, the sulphuric acid rapidly absorbs the vapour rising from the water; fresh vapour is immediately formed, and in a few minutes, if the circumstances are favourable, speculæ of ice are seen to form on the surface of the water.

When aqueous vapour is condensed into fluid in the atmosphere, heat is produced; and the formation of rain, hail, and snow, tends to mitigate the severity of the winter. In the summer, evaporation is constantly tending to cool the surface. The melting of the polar ice moderates the heat that would arise in the northern regions from the constant presence of the sun during the polar summer. And the evolution of heat during the congelation of water, prevents too great a degree of cold, and renders the transitions of temperature more slow and gradual.

12. When the forms of bodies are changed by mechanical means, or when mechanical forms are made to act upon them, there is usually a change of temperature. A piece of caotchouc extended and suffered to contract rapidly by mechanical means, becomes hot; a nail is easily made red-hot by a few well directed blows of the hammer; and by the friction of solids, considerable in-

crease of temperature is produced; thus the axle-trees of carriages sometimes inflame.

By strong pressure, fluids even are made luminous, as has been lately shewn by M. Dessaignes.

When an elastic fluid is compressed by mechanical means, its temperature is raised; and when the compressing forces are great and rapidly applied, the effect is such as to cause the ignition of bodies. A machine for setting fire to the tinder of the agaric, by the compression of air, has been for some time in use.

When air is made to expand by removing compressing forces, a diminution of temperature is occasioned. Thus the mercury in the thermometer sinks at the time of the rarefaction of air, by exhausting the receiver of an air-pump.

In the common language of chemistry, it may be said that the capacity of elastic fluids for heat is diminished by compression, and increased by rarefaction; and it is probable that when the volumes of elastic fluids are changed by change of temperature, there is likewise a change of capacity, and on these ideas, it is easy to account for the correspendence between the diminution of the temperature of the atmosphere and its heights; for if it be conceived that the capacity of air rarefied by heat, increases as it ascends, the heat of temperature which was the cause of its ascent, must, at a certain elevation, become heat of capacity: and the higher and more rarefied the air, the more it is removed from the source of heat, and the greater its power of diminishing temperature.

A very curious phenomenon is produced during the action of the fountain of Hiero at Schemnitz in Hungary; the air in the machine is compressed by a column of water, 260 feet high, and when a stop-cock is opened so as to suffer air to escape, its sudden rarefaction produces a degree of cold which not only precipitates aqueous vapours, but causes it to congeal in a shower of snow, and the pipe from which the air issues, becomes covered with icicles. Dr. Darwin has ingeniously explained the production of snow on the tops of the highest mountains by the precipitation of vapour from the rarefied air which ascends from plains and vallies. The chain of the Andes, placed almost under the line, rises in the midst of burning sands: about the middle height is a pleasant and mild climate: the summits are covered with unchanging snows; and these ranges of temperature are always distinct; the hot winds

from below, if they ascend, become cooled in consequence of expansion, and the cold air, if by any force of the blast it is driven downwards, is condensed, and rendered warmer as it descends.

It seems probable that the capacity of solids and fluids is increased by expansion, and diminished by condensation; and if this is the case, the additions of equal quantities of heat will give smaller increments of temperature at high than at low degrees, which must to a certain extent render the thermometer inaccurate in the highest degrees, though probably only to a very small extent, of little importance as to all practical purposes; and this cause of inaccuracy appears to be counteracted by another, that fluids seem to be more expansible by heat in proportion as their temperature is higher.

13. In all chemical changes there is an alteration of temperature; and in most instances when gases become fluids, or fluids solids, there is an increase of temperature; and *vice versâ*, there is usually a diminution of temperature when solids become fluids, or fluids, gases. For instance, when the highly inflammable substance called phosporus, some of whose properties will be hereafter described, is burnt in the air, it is found to condense a particular part of the air, and a high temperature is produced during the process. When a solid amalgam of bismuth, and a solid amalgam of lead, are mixed together, they become fluid, and the thermometer sinks during the time of their action.

There are, however, a number of cases in which, though gaseous bodies or fluids are formed from solids, an increase of temperature occurs: thus, in the explosion of gunpowder a large quantity of æriform matter is disengaged, yet a violent heat is produced.

And there is an instance in which at the time of the separation of two species of gaseous matter from each other, which is connected with expansion, there is an increase of temperature; thus, when a little of the gas which I have named Euchlorine, and which consists of the substance called by the French chemists oxymuriatic gas, and oxygene gas, is gently heated in a small glass tube over mercury, an explosion takes place, fire appears, and yet the two gases occupy a greater volume than before the explosion.

14. As attempts have been made to account for attraction, by

the supposition of the existence of a peculiar matter, so *calorific repulsion* has been accounted for by supposing a subtile fluid, capable of combining with bodies, and of separating their parts from each other, which has been named the *matter of heat*, or *caloric*.

Many of the phenomena admit of a happy explanation on this idea, such as the cold produced during the conversion of solids into fluids or gases, and the increase of temperature connected with the condensation of gases and fluids; but there are other facts which are not so easily reconciled to the opinion: such are the production of heat by friction and percussion; and some of the chemical changes which have been just referred to. When the temperature of bodies is raised by friction, there seems to be no diminution of their capacities, using the word in its common sense; and in many chemical changes connected with an increase of temperature, there appears to be likewise an increase of capacity. A piece of iron made red-hot by hammering cannot be strongly heated a second time by the same means, unless it has been previously introduced into a fire. This fact has been explained by supposing that the fluid of heat has been pressed out of it, by the percussion, which is recovered in the fire; but this is a very rude mechanical idea: the arrangements of its parts are altered by hammering in this way, and it is rendered brittle. By a moderate degree of friction, as it would appear from Rumford's experiments, the same piece of metal may be kept hot for any length of time; so that if heat be pressed out, the quantity must be inexhaustible. When any body is cooled it occupies a smaller volume than before: it is evident, therefore, that its parts must have approached toward each other: when the body is expanded by heat, it is equally evident that its parts must have separated from each other. The immediate cause of the phenomena of heat then is motion, and the laws of its commuuication are precisely the same as the laws of the communication of motion.

Since all matter may be made to fill a smaller volume by cooling, it is evident that the particles of matter must have space between them; and since every body can communicate the power of expansion to a body of a lower temperature, that is, can give an expansive motion to its particles, it is a probable inference that its own particles are possessed of motion; but as there

is no change in the position of its parts as long as its temperature is uniform, the motion, if it exists, must be a vibratory or undulatory motion, or a motion of the particles round their axes, or a motion of particles round each other.

It seems possible to account for all the phænomena of heat, if it be supposed that in solids the particles are in a constant state of vibratory motion, the particles of the hottest bodies moving with the greatest velocity and through the greatest space; that in fluids and elastic fluids, besides the vibratory motion, which must be conceived greatest in the last, the particles have a motion round their own axes, with different velocities, the particles of elastic fluids moving with the greatest quickness: and that in ethereal substances the particles move round their own axes, and separate from each other, penetrating in right lines through space. Temperature may be conceived to depend upon the velocities of the vibrations; increase of capacity on the motion being performed in greater space; and the diminution of temperature during the conversion of solids into fluids or gases, may be explained on the idea of the loss of vibratory motion, in consequence of the revolution of particles round their axes, at the moment when the body becomes fluid or aëriform, or from the loss of rapidity of vibration in consequence of the motion of the particles through greater space.

If a specific fluid of heat be admitted, it must be supposed liable to most of the affections which the particles of common matter are assumed to possess, to account for the phænomena; such as losing its motion when combining with bodies, producing motion when transmitted from one body to another, and gaining projectile motion, when passing into free space: so that many hypothesis must be adopted to account for its mode of agency, which renders this view of the subject less simple than the other. Very delicate experiments have been made which shew that bodies when heated do not increase in weight. This, as far as it goes, is an evidence against a specific subtile elastic fluid producing the calorific expansion; but it cannot be considered as decisive, on account of the imperfection of our instruments; a cubical inch of inflammable air requires a good balance to ascertain that it has any sensible weight, and a substance bearing the same relation to

this, that this bears to platinum, could not perhaps be weighed by any methods in our possession.

Some arguments have been raised in favour of the existence of a specific fluid of heat, from the circumstances of the communication of heat to bodies in exhausted receivers, and from the manner in which they are affected by this heat; but there are no means known in experimental science of producing a perfect vacuum; even the best Torricellian vacuum must contain elastic matter. The great capacity of such highly rarefied matter is an obstacle to the indication of temperature; but supposing a communication of heat, the laws must be analogous to those of heat communicated to common air. If a long *cylinder* of metal, placed perpendicularly, be heated in the middle, the warmest part will be above, from the ascent of heated particles of the elastic medium; but if a *sphere* be heated in the middle, the hottest portion will be below, as the heated elastic matter must remain longer in contact with the inferior than with the superior portion.

[*Sir H. Davy's Elem. of Chem. Phil.*

For the following curious Table of the comparative effects of Heat upon different substances we are indebted to Dr. Young; in order to comprehend which it will be necessary to observe, that the letters W. and F. relate to the respective thermometers of Wedgwood and Fahrenheit, for a knowledge of the principles of which we must refer the reader to the second general division of the present work, or that part of the Gallery of Nature and Art which relates to the latter subject.

Wedgwood's greatest heat	240° W.	
Nankeen porcelain withstands	160	
Best Chinese porcelain softened	156	
Pig iron melts completely	150	
Bristol porcelain withstands	135	
Pig iron begins to melt W.	130 W.	17977 F.
Iron, pure nickel, and pure cobalt melt, Bergman		1601
Smith's forge	125	
Plate glass furnace	124	
Bow porcelain vitrifies	121	
Inferior Chinese porcelain softens	120	
Flint glass furnace	114	
Derby porcelain vitrifies	112	
Chelsea porcelain vitrifies	105	

Stone ware, pots de grès, baked	102	
Welding heat of iron	95	
Worcester porcelain vitrifies	94	
Welding heat of iron begins	90	
Cream coloured ware baked	36	
Flint glass furnace, weak	70	
Working heat of plate glass	57	
Delf ware baked	41	
Fine gold melts, W.	32° W.	5237° F.
Bergman		1301
Settling heat of flint glass	29	
Fine silver melts W.	28	4717
Bergman		1000
Swedish copper melts, W.	27	4587
Bergman		1450
Brass melts	21	
Enamel burnt on	6	
Red heat, visible by day-light, W.	0 W.	1077
Bergman		1050
Red heat, visible in the dark	— 1 W.	947
Antimony melts, Bergman		809
Zinc melts, Bergman		699
Mercury boils		660 or 655
Expressed oils boil		600
Sulfuric acid boils		590 546
Steel becomes deep blue		580
Oil of turpentine boils		560 324.5
Lead melts		540
Biot		504
Bergman		595
Bishmuth melts		460
Bergman		494
Steel becomes straw-coloured, the best temper for penknives		460
Lead 4, tin 1, melts		460
Tin melts		408
Biot		410
Bergman		415
Chrichton, Ph. M.		442
Bismuth 1, tin 1, melts		283
Nitric acid boils		242
Saturated solution of salt boils		218
Water boils, the barometer at 30		212
Bismhut 5, tin 3, lead 2, melts		212
Bismuth 8, lead 5, tin 3, melts		210

Alcohol boils	174
Serum and albumen coagulate	156
Bees-wax melts	124
Heat of tea and coffee	120 to 140
Feverish heat	107 to 112
Heat for incubation	108
A pleasant bath	92 to 106
The interior bath at Edinburgh	100
Blood heat	96 to 100
Temperate air	62
Ice melts	32° F.
Wedgwood thinks the freezing point of vapour a little higher	
Milk freezes	30
Sea water freezes	28
Alcohol 10, water 14, by weight, freezes	21
Wine freezes	20
Alcohol 1, water 3, freezes	7
Alcohol 1, water 5, freezes	— 7
Alcohol 2, water 1, freezes	— 11
Mercury freezes contracting about 1·23	— 39

[*Young's Nat. Phil.*

SECTION II.

Variation of Local Heat.—By James Six, Esq.

To investigate the variation of local heat, I made the following experiments. On Sept. 4, 1783, I placed thermometers in 3 different stations; one on the top of the high tower of Canterbury cathedral, about 220 feet from the ground; another at the bottom of the same tower, at about 110 feet; and a 3d in my own garden,* not more than 6 feet from the ground. They were all carefully exposed to the open air in a shady northern aspect; the lowest was as little liable to be affected by the reflection of the sun's rays as the elevation would permit, the second still less, and the highest not at all. They thus remained in their several places, where I visited them daily for 3 weeks, and minuted down the greatest degree of heat and cold that happened each day and night in their respective stations, by a peculiar thermometer.

By these observations it appears that, notwithstanding some irregularities, the heat of the days at the lowest station always exceeded that at the middle, and still more the heat at the upper

* Situated not far from the cathedral, at the extremity of the buildings on the north side of the city.—Orig.

station. As in many instances the higher regions of the atmosphere have been found to be colder than the lower, and the thermometer in the garden was more liable to be heated by the reflection of the sun's rays from the earth than the upper ones, a difference of this kind might have been expected. But I was greatly surprised to find the cold of the night at the lowest, not only equal to, but very frequently exceeding the cold at the higher stations. As I wished to know, whether these variations would continue the same in winter, when the weather was colder, and whether a thermometer, placed at some distance from the city, having an elevation equal to that on the top of the cathedral tower, would agree with it; on Dec. 19, 1783, I disposed the 3 thermometers in the following manner: one in my garden; one on the top of the high tower, as before; and the third on the top of St. Thomas's hill, about a mile distant from the city, where, at 15 feet from the ground, it was nearly level with that on the cathedral tower. The weather at this time proving cold, favoured the experiment; and I now found the several thermometers nearly agreeing with each other in the day-time; but in the night, the cold at the lower station exceeded the cold at the higher ones rather more than it did in the month of September, when the weather was warmer.

At the time of taking these thermometrical observations, I likewise noted the different dispositions of the atmosphere in other respects: such as the pressure, moisture, and dryness of the air; force and direction of the winds; quantity of rain; whether the appearances of the sky were clear or cloudy, &c. as I apprehended the local variation of the thermometers might, in a certain degree, correspond with some particular change in the state of the atmosphere. The event answered my expectation in a singular manner in respect to the nocturnal variation; for it generally happened, that when the sky was dark and cloudy, whatever was the condition of the atmosphere with regard to the other particulars above enumerated, the thermometers agreed pretty nearly with each other; but, on the contrary, whenever the sky became clear, the cold of the night at the lowest station in the garden constantly exceeded the cold at the top of the cathedral tower, where the instrument was placed 220 feet from the ground, entirely exposed to the open air, wind, dews, and rain, in a shady northern aspect.

The local variations in the day-time seemed to be regulated by

the general degree of heat only, without being affected by any other particular disposition of the atmosphere, or the clearness or cloudiness of the sky, as the nocturnal variations were. In the month of September, when the glasses rose from 60° to 70°, the heat at the lower station constantly exceeded the heat at the upper station; and in some measure proportionably, as the weather was hotter *. In December and January, when from below 30° they seldom rose to 40°, the local variation in the day-time nearly ceased, or was found in very small degrees inclining sometimes one way, sometimes the other.

That the clearness of the sky should contribute to the coolness of the air in the night, is not at all surprising; but that, whenever the sky becomes clear, the cold should seem to rise from the earth, and be found in the greatest degree, as long as it continues clear, in the lowest situation, seems a little extraordinary: this, however, appeared to be the case, both in the warmer and in the colder weather, during the whole time these observations were taken. About noon, on the 3d of January, the sky becoming clear, the air got cooler; and going into my garden, about 8 in the evening, I perceived the surface of the ground, which had been wet by the rain in the forenoon, began to be frozen. Looking immediately at the thermometer, I saw the mercury at $33\frac{1}{2}$°; and observing a piece of wet linen hanging near the glass, not 5 feet from the ground, I took it into my hand, and found it not in the least frozen; by which it appeared, that the degree of cold which had frozen the surface of the ground, had not then ascended to the glass, nor to the linen, and consequently had not been communicated to the air 5 or 6 feet above the earth. The next day I found, as expected, a considerable local variation; the index for the cold of the night in the garden being at 32°, that on the hill being at $35\frac{3}{4}$°, and that on the top of the tower at $37\frac{1}{4}$°. Probably the weather did not continue clear the whole night; if it had, it is likely the degrees of cold would have been found proportionably greater at every station. On the morning of the 4th there fell a

* As the heat at the lower station exceeded the heat at the upper ones, when the weather was hot; and equally so, whenever the sky was cloudy, as well as when it was clear; it appears, that the glass at the lower station was not materially affected by the reflection of the sun's rays from the earth, as at first I apprehended it would be. —Orig.

misty rain, which continued only till noon, when the sky became clear again, and continued so till the 7th; during which time the nocturnal heights of the thermometers differed considerably from each other; but on the sky becoming cloudy, the local variation ceased.

By experiments of this kind, it may possibly in some measure be found, how far evaporations from the earth, at certain times, or vapours ascending, descending, or meeting, in different parts of the atmosphere, may increase or diminish the heat of the air in those places; or whether different degrees of heat and cold, subject however to change, may not be found in different strata of air, or vapour, floating in different parts of the atmosphere; or in what degree and proportion the cold increases at different altitudes, and in different seasons of the year; whether the cold, which is known to be very intense in the summer time on the tops of high mountains, receives a proportional increase, or be not less subject to variety by the return of winter and summer, night and day, than what we experience in the plains below.

[*Phil. Trans.* 1784.

Mr. Six afterwards continued a similar series of experiments throughout an entire year, in order to ascertain how far the results might coincide with those of the preceding paper, which were confined to a part of the autumn and of the winter. To this end, as he tells us, in another paper communicated to the Royal Society in the year 1788, he suspended proper thermometers in a shady northern aspect, in the open air, at different heights; one in the garden at 9 feet, and another in the Cathedral Tower, 220 feet from the ground; continuing his journal, with the omission of a few days only, from July 1784 till July 1785. The result entirely corresponded with what was before observed respecting the nocturnal diminution of heat, and the particular state of the atmosphere requisite to produce it. From the 25th to the 28th of October, the heat below in the night exceeded, in a small degree, the heat above, at which time there was frequent rain, sometimes mingled with hail. From the 11th to the 14th, and also on the 31st, there was no variation at all; during which time likewise the weather was rainy; all the rest of the month proving clear, the air was found colder below than it was above, sometimes 9 or 10 degrees. On cloudy nights, in June, the lowest thermometer

sometimes showed the heat to be a degree or two warmer than the upper one; but in the day-time the heat below constantly exceeded the heat above more than in the month of October.

Being desirous of knowing whether the nocturnal refrigeration increased on a nearer approach to the surface of the earth, Mr. S. placed, in the midst of an open meadow, on the bank of the river, two thermometers; one on the ground, and the other six feet above it: with these, and the two others before-mentioned, one on the tower, and the other in the garden, he made observations from the 10th to the 23d of October, 1786. Here he found, as before, the nocturnal variations entirely regulated by the clearness or the cloudiness of the sky; and though they did not always happen in the same proportion to the respective altitudes, yet, when the thermometers differed at all, that on the ground was always the coldest.

Finding so considerable a difference as $3\frac{1}{2}°$ within six feet of the earth's surface, Mr. S. increased the number of thermometers in the meadow to four; one of them he sunk in the ground, another he placed just on the ground, a third he suspended at three feet, and a fourth at six feet from the ground. At the same time, he placed three thermometers in an open garden on St. Thomas's Hill, where the land is level with the Cathedral Tower, and about a mile distant from it: here he likewise put one in the ground, another just on it, and suspended a third six feet above it. With these seven thermometers and the two before-mentioned (in the city), he continued a diary for 20 days, taking also every morning the temperature of the water in the river; but the weather proving cloudy soon after, the thermometers hardly varied at all, seven or eight days only excepted. After this time, he never rectified them but when the appearance of the weather gave reason to expect that they would vary considerably: by which it appears, that the cold in the night was generally greater in the valley than that on the hill; but that the variations between the thermometers on the ground, and those six feet above them, were often as great on the hill as in the valley.

From the foregoing experiments it appears, that a greater diminution of heat frequently takes place near the earth in the night-time, than at any elevation in the atmosphere within the limits of Mr. Six's inquiry; and that the greatest degrees of cold are at such times always found nearest to the surface of the earth; that this is

a constant and regular operation of nature, under certain circumstances and dispositions of the atmosphere, and takes place at all seasons of the year; that this difference never happens in any considerable degree but when the air is still, and the sky perfectly unclouded; but the moistest vapour, such as dews and fogs, did not, as far as he could perceive, at all impede, but rather increase the refrigeration. In very severe frosts, when the air frequently deposits a great quantity of frozen vapour, he generally found it greatest; but the excess of heat, which in day-time, in the summer season, was found at the lower station, in the winter diminished almost to nothing.

The foregoing experiments related to the difference of heat which, at certain times, is found at different altitudes; the following to the different degrees of heat observed at different situations in respect to the sea-shore. Mr. S. exhibits a set of corresponding observations; among which are some taken at Chislehurst, by the Rev. Mr. Wollaston: others, at the same time, were taken in Mr. S.'s garden, and on the Cathedral Tower: and others on the sea-shore, about seven miles N. N. W. from Canterbury, where the thermometer was suspended about 40 feet above high-water mark, fourteen from the ground, and about 100 yards from the sea. Hence it appears that every night, one only excepted, during that time, the air was coldest at Chislehurst; and that the mean heat at the sea-shore was equal to that on the tower at Canterbury. In the month of June, the cold was still greater in the night at Chislehurst than at any of the other places, excepting where there appeared two currents of wind, the upper current from the S. W. and the lower from the N. E.; at which time also there was the greatest difference between the thermometer in the garden and that on the tower.

The following experiments relate to the variation of local heat in the earth itself; the diversity of which appears from the different heat of the water issuing from it at different places. It has been conjectured, that the diversity of the temperature of springs may probably depend on their different elevations in the earth, with respect to the level of the sea. Two remarkably deep wells, both near the sea-shore, and not far distant from Canterbury, gave a favourable opportunity of making experimental inquiry into this matter; especially as the situation of the two springs differed considerably from each other in respect to the level of the sea. One of

these is a well in Dover Castle, which is sunk 360 feet through the high cliff of chalk on which the castle stands, and the depth of the well is nearly equal to the height of the cliff from the sea. The other is King's Well at Sheerness, which was sunk 330 feet through also one entire stratum of firm clay, where the surface of the ground is only four feet above high water. Supposing, therefore, the spring in Dover well to lie level with the sea, the spring of the well at Sheerness lies 326 feet below it; a circumstance extremely favourable to the experiment. The temperature of the springs he took in the following manner. After fathoming each well with a line and plummet, he let one thermometer down to the bottom, and fixed another on the line, so as to reach to half the depth only, keeping a third to take the temperature of the air at the top:—

Sept. 28, 1784.—Temperature of the water in the new well in Dover Castle:

	Deg.
By the thermometer at the top....	56
By ditto at the middle............	52
By ditto at the bottom............	48¾

Found the well 360 feet deep with 21 feet water.

Oct. 6, 1784.—Temperature of the water in King's Well at Sheerness:

	Deg.
By the thermometer at the top.....	53
By ditto at the middle............	51
By ditto at the bottom............	56

Found the well 280 feet deep* with 180 feet water.

About noon was the time of day when Mr. S. made the experiments at both places, and the top of the respective wells varying from each other depended wholly on the accidental temperature of the atmosphere at the time; but that the thermometer at half the depth of the well at Dover gave nearly the mean heat of the top and bottom, while that in a corresponding situation in the well at Sheerness gave it colder than either top or bottom, he attributes to the following circumstance. Over the well at Sheerness, a machine is erected, which raises the water by means of a horizontal windmill, working an endless chain. This chain, consisting of jointed double bars, with a number of buckets fixed at certain distances from each other, continually descending into, and ascending out of the water, to an elevation of eight or nine feet above the top of the well, may be supposed to reduce the water as far as it reaches to the mean temperature of the air above; and thus he found it; for 51° had been the mean temperature of the air near the sea-shore for several days before. At the bottom of the well, near to which the

* The sand brought up from the bottom of the well, by the force of the spring, has reduced it to its present depth.—Orig.

chain never descends, he found the temperature 56°; above 7° warmer than that at Dover well.

The water at the bottom of these wells is, he presumes, too deep beneath the surface of the earth ever to be affected by the temperature of the atmosphere; for if the heat of the summer could have had any influence on either of them, that at Dover must have been most considerably affected by it, especially in the month of September; and the air was something warmer when the experiment was made at Dover than at Sheerness. From the nature of the different kinds of strata in which these wells are dug, had they been in all other circumstances the same, one might reasonably expect to find the warmer spring in the chalk, and the colder in the clay; but here the reverse is seen, without any apparent local cause, except the different elevations of the springs in respect to the level of the sea.

[*Phil. Trans. Abr.* 1784.

SECTION III.

Variation of Heat in Countries best known, or that are most exposed to it.

According to Cotte's General Aphorisms, there is little variation of heat between the tropics: it becomes greater on plains than on hills: it is never so low near the sea as in inland parts: the wind has no effect on it; its maximum and minimum are about six weeks after the solstices: it varies more in summer than in winter: it is least a little before sun-rise: its maxima in the sun and shade are seldom on the same day: it decreases more rapidly in the autumn than it increases in summer. A cold winter does not forbode a hot summer.

Kirwan says, that the mean heat at the sea is 84°—53 (sine lat.)^2. From this we must deduct for elavation, 1° for each 800 feet that we ascend perpendicularly, where the declivity is about 6 feet per mile; where 7 feet, 1° for 600 feet; where 13 feet, for 500; where 15 or more, 1° for 400. For the distance from the sea, we must add 1° for each 50 miles, between 10° and 20° latitude; between 25° and 30°, 1° for 100 miles: between 30° and 35°, we must deduct 1° for 400 miles; between 35° and 70° for 150. It seldom freezes in latitude below 35°, and seldom hails beyond 60°;

between these limits it generally thaws when the sun's altitude is above 40°. The greatest cold is usually half an hour before sunrise; the greatest heat at the equator about one o'clock; further north it is later: in latitude 50° about half past two. In latitude above 48° July is warmer than August: in lower latitudes colder. At Petersburgh the greatest summer heat is usually 79°. In every habitable climate there is a heat of 60° or more, for at least two months.

According to Cavallo, the greatest heat of the day in July is before two o'clock; according to others, about half way between noon and sunset.

Found the springs at Kingston in Jamaica, about 80°; after a gentle ascent of two miles, 79°; cold spring, nearly 1400 yards above the sea, was $61\frac{3}{4}$°; the variation is 1° for 230 feet. The extremes at Kingston were 69 and 91°: the usual height in the cold season from 70° to 77°, in the hot from 85° to 90°. At Brigthelmstone the heat of a well was 50°; at Bromley, in November, $49\frac{1}{2}$; and the mean between the heat of London, at sunrise and at two o'clock, is about 49°·2. Kirwan gives 52° for the mean heat of London. The wells at New York vary from 54° to 56°.

From the observations of the Royal Society, the mean temperature in London is 50° 5′, varying in different years from 48° to 52°; the mean of the greatest cold and greatest heat is 50° or 49°.

The mean of the greatest cold and heat at Paris is 54°·5. According to Cotte the mean temperature is $9\frac{1}{2}$° Reaum. or 53°·4 Fahr. In the summers of 1753, 1765, and 1793, the heat in France was 104° Fahr.

The mean temperature at Columbo is 79°·5; the utmost variation 13°.

In Senegal, Lalande mentions a heat of 113°.

Rosier IV. 82, gives an account of a heat at $34\frac{1}{2}$° Reaum. or 109 Fahr. at Pekin that was fatal to more than 10,000 persons.

In the Asiatic Mirror, Mag. for 1789, we have a statement of the heat at Cawnpore from April 7 to May 6. For twenty-one days (from April 14 to May 6,) the mean heat without doors at 2 P. M. was 127° Fahr.—the greatest heat, April 18, 144°. The mean heat at night behind a tattoe or wet mat, was 93°; the mean

heat at two o'clock was 79°, being at that time 48° lower than in the open air.

The following Table and remarks on the heat of the different seasons in India, is of too much consequence to be abridged. The observations were made at Allahabad, by Sir Robert Barker, in 1767, and was communicated to the Royal Society in 1775.

The greatest part of the observations at Allahabad were made within doors; several were made within a tent placed under the shade of trees, some in the open air in the sun, and some in the open air in the shade; but there is no regular series of observations in any one place; nor were they made at stated times of the day. Though a thermometer kept within doors is but a very indifferent measure of the heat of any climate; yet as I have not seen any thermometrical observations made in that country, except a few during the heats of the summer, and printed in the Philos. Trans. vol. lvii. p. 218, I have set down the greatest and least heights met with in each month.

	Least.	Great.		Least.	Great.		Least.	Great.
January	58	72	May	72	101	September	78	83
February	60	84	June	81	99	October	72	87
March	62	94	July	81	90	November	52	86
April	79	96	August	80	86	December	51	64

From the 3d of May to the 4th of June inclusive, a thermometer placed within a tent, under the shade of trees, was almost every day above 100°, and several times above 109°, once at 112°. The trees under which the tent was placed, formed a very thick shade; so that probably these heights are more likely to fall short of the true heat of the open air at that time, than to exceed it. The least height he met with of the thermometer in the open air in the shade, is 42°; which it was at twice in the month of January, at 7 A. M. The greatest heat is on June 9th, at noon, when it was at 114°, the sky cloudy; the thermometer within doors at the same time 95°, which is less than it had frequently been in the month of May; so that it seems likely, that the heat of the open air in May had frequently been above 114°. During the voyage to England, the thermometer was placed in the round-house, and was observed regularly at eight in the morning, at noon, and at three in the afternoon; the winds and weather are also set down. The round-house is one of the uppermost rows of cabins, and is

reckoned the coolest and most airy part of the ship. From February 13 to April 7, between Madras and the southern tropic, the thermometer was constantly between 77° and 86°, and very seldom lower than 80°. From that to April 23, lat. 34° 12′ about 15° E. of the Cape of Good Hope, between 70° and 80°. Thence to May 20, at St. Helena, between 62° and 72°. Thence to August 2, in lat. 43° 14′ N. between 71° and 80°; and thence to August 15, in the British Channel, between 62° and 70°. At land it is well known that the heat is usually considerably greater in the middle of the day, than in the morning or night; but it appears from these observations, that in the open sea there is scarcely any sensible difference; for in settled weather, the difference between the different times of the day was rarely more than 1°, oftener none at all. In unsettled weather there was frequently a difference of 2°, sometimes 4°, scarcely ever more: but then there seems no connection between this difference and the time of the day, it being as often colder in the middle of the day than in the morning or evening, as warmer. There is added a register of the thermometer, in the soldier's barracks at Allahabad, on June 8, 1769, when from ten in the morning to eight in the afternoon it stood constantly above 100°, in the hottest part of the day at 107°, and during the whole night between 99° and 98°.

We shall throw a more general glance over a few other parts of the world, where also the heat is frequently felt with a very oppressive force.

It is almost unnecessary to observe, after what we have remarked already, that in the levels or mean elevations of tropical regions, ice and snow are unknown, so that the natives would as soon expect that marble should melt and flow in liquid streams, as that water, by freezing, should lose its fluidity, and be converted into a solid body. To talk to them of rain or vapour converted into snow or hail, would excite their ridicule instead of obtaining their belief.

Egypt. This country, being situated between two ranges of mountains, and having a sandy soil, is in summer very hot, and even in winter a considerable degree of heat is felt toward the middle of the day, though the nights and mornings are then very cold. The severity of winter is felt about the beginning of February.

ARABIA. The countries so called, in their full extent, are computed to be thirteen hundred miles in length, and twelve hundred in breadth where broadest; the most southerly part lies in 12° 30′, and the most northerly in 32° north latitude. It consists of three grand divisions: Arabia Felix, or the Happy, which is the most southern, and the largest part; Arabia Deserta, or the Desert, which stretches to the north; and Arabia Petræa, or the Stony, which lies on the north-west, and is by far the smallest of the three divisions. That part of Arabia which lies within the tropic is excessively hot, and in many places unhealthy, particularly those parts which are situated on the coast of the Red Sea. The winds are also hot and suffocating, and the sands not only extremely troublesome but dangerous, they being sometimes driven by the winds in such prodigious clouds that whole caravans have been buried and lost by a single storm. The southern part of Arabia, distinguished by the name of the "Happy," would be considered as having little claim to that title, by a stranger traversing its shores, but should such an one be placed in its middle regions, beneath the balm-dropping woods, and amidst the verdant vales, where the fruits of every climate court the taste, and the breezes of Cassia refresh the senses, he would acknowledge that the ancients very justly bestowed on the country that emphatical appellation. The Desert part of Arabia with equal propriety bears that name, the soil consisting of barren sand. "In the dreary waste of Arabia," says Mr. Gibbon, "a boundless level of sand is intersected by sharp and naked mountains, and the face of the desert, without shade or shelter, is scorched by the direct and intense rays of a vertical sun." There are, however, large flocks of sheep and herds of cattle near the Euphrates, where the soil is good; there are also great numbers of ostriches in the desert, and in several places a fine breed of camels. Arabia Petræa is also rendered famous on account of the wanderings of the children of Israel there during forty years. "People are not there entertained," says Dr. Shaw, "with a view of pastures covered with flocks, or vallies enriched with corn. There are no oliveyards or vineyards, but the whole is a desolate, lonesome wilderness, only diversified by sandy plains, mountains of naked rocks, and sandy precipices. This desolate country is never refreshed with rain, ex-

cept sometimes at the equinoxes; and the few hardy vegetables seen in the clefts of the barren rocks, or wildly dispersed on the sandy plains, are shrunk by a perpetual drought; for the dews of the night are in a manner rendered insufficient for the purposes of vegetation, by the scorching heat of the sun during the day. The intense cold of the one, and the heat of the other, clearly account for the wise provision of providence in spreading over the Israelites a cloud to be a covering by day, and a fire to give light (and perhaps heat) in the night season."

Though the land appears so desolate, yet the surface of the Red Sea, when calm, discovers in some places, such a diversity of marine vegetables, that they resemble a forest under water; and its shores display a great variety of star fishes, urchins, and fish-shells of great variety and beauty: but in passing over the deserts the traveller is much annoyed by swarms of locusts and hornets, and is likewise in danger from vipers, but the reptiles of the lizard kind, from the variety of their shapes and spotted skins, he views with more pleasure and safety. "Whilst travelling," says the learned and judicious author above quoted, "the heavens were every night our only covering, a carpet spread on the sand was our bed, and a change of raiment made up into a bundle served for a pillow. Our Camels (for horses and mules require too much water to be employed in these deserts) lay round us in a circle, with their faces looking from us, while their loads and saddles were placed by us behind them. In this situation they served as guards and centinels; for they are watchful animals, and awake at the least noise."

In proceeding through these long and dreary deserts, no refreshment is to be procured, except water from springs which are sometimes met with in the course of four or five days progress, so that, previous to setting out, every necessary must be provided for the tedious and dangerous journey; for which purpose a number of goats' skins are obtained, which are filled with water as often as it can be found; balls made up of the flower of beans or barley are the food for the camels, whilst wheat flour, biscuit, potted flesh, honey, oil, vinegar, olives, and such other articles as will keep, form the common articles for the travellers themselves. They take with them also wooden dishes, and a copper pot, for their kitchen furniture. When obliged to boil or bake, they make use of

camel's dung, which they find scattered on their way, and which the camels of some preceding caravan had let fall; this, when exposed a day or two in the sun, catches fire like touchwood, and burns as bright as charcoal. No sooner is the food prepared, whether potted flesh boiled with rice, lentil soup, or unleavened cakes, served up with oil or honey, than one of the Arabs, placing himself on the highest station he can find, calls out three times with a loud voice, to invite all his brethren, the sons of the faithful, to come and partake of it, though none of them are perhaps within an hundred miles of him. This custom the Arabs constantly observe, as a token of their benevolence.

In these deserts the sky is generally clear, the winds blow briskly in the day, and cease in the night. Sandy and level spots are as fit for astronomical observations as the sea, which they nearly resemble. "It was surprising to observe," says the writer above quoted, "in what an extraordinary manner every object seemed to be magnified, for a shrub appeared as big as a tree, and a flock of achbobbas (birds nearly resembling the stork) might be mistaken for a caravan of camels." This seeming collection of waters always advances about a quarter of a mile before the travellers, while the intermediate space appears of one continued glow, from the quivering undulating motion of that quick succession of exhalations raised by the powerful influence of the sun. The violent heat draws up even the moisture from the carcases of the camels and other animals, which, having died, lie exposed in these deserts, and prevents their putrefaction, in consequence of which they continue there several years, moisture being one of the most active accessaries in the putrefactive process. To the same cause, added to the coldness of the nights, may be attributed the plentiful dews that frequently wet travellers to the skin; but the sun no sooner rises, and the air becomes heated, than the mists are dispersed and the moisture of the sands are exhaled.

What is called "the Desert of Sinai," is a beautiful plain near nine miles long, and above three in breadth; it lies to the north-east, but to the southward is closed by some of the lower eminences of the mountain of this name, while other parts of the mountain make such encroachments upon the plain as to divide it in two, each portion so capacious as to be sufficient to receive the whole camp of the Israelites. That which lies to the eastward of the

mount is perhaps the desert of Sinai, properly so called, where Moses saw the angel of the Lord in a burning bush. Over the place where tradition has fixed this divine appearance to have been made, is erected a convent, dedicated to St. Catherine, which belongs to the Greeks; it is three hundred feet square, and above forty in height. On the spot where they suppose the burning bush to have stood, is a little chapel, where the monks, in imitation of Moses, put off their shoes whenever they enter it. This, with some other chapels, dedicated to particular saints, is included within the church of the Transfiguration, a large and beautiful structure, supported by two rows of marble columns.

In that part of Arabia Petræa which geographers have distinguished by the name of the "Desert of Tadmore, or Palmyrene," formerly stood the magnificent city of Palmyra. It was situated in about 33° N. latitude, two hundred miles to the south-east of Aleppo. The heat is here also intense, and frequently intolerable.

ZAHARA, or ZAARA. The proper use to be drawn from a survey of the burning, barren and inhospitable parts of the globe, is to teach us to prize our own fruitful and temperate climate, which supplies the body with wholesome aliment, gratifies the senses by the exhibition of pleasing objects, and furnishes the best opportunities to the mental powers of man for the acquisition of useful knowledge, amidst the rich stores of science and philosophy. When perusing the accounts of travellers who have endured such hardships and fatigues as to men habituated to the regular and quiet walks of life would be deemed insupportable, whilst their sufferings tend to interest our feelings, a consciousness of our own security should inculcate content and self-satisfaction.

Those parts of the continent of Africa which lie under the tropic of Cancer, and in some places extend ten degrees to the south of it, are sandy and desert as far as from the Atlantic Ocean on the west, to about the twenty-fifth degree of east longitude. They comprehend a space of more than fifteen hundred miles from east to west, and sometimes run six hundred miles from north to south. This large tract of land is divided by the natives, who are Arabians, into three general divisions, Capel, Zaara, and Asgar, which signify the sandy, stony, and marshy deserts; but European geographers have partitioned the country into seven provinces, which are named Zanaga, Zuenziga, Twarga or Hayr, Lempta or Iguidi, Bardoa, Bornou, and Gauga.

Travelling is here extremely fatiguing and dangerous, especially if the summer prove dry, scarcely a drop of water being to be seen for thirty leagues together; and when any is found, it is so brackish, as to be equally unwholesome and unpalatable. Nor do the cattle feed better, the barren earth not yielding so much as a blade of grass, or any thing for their sustenance, which obliges the passengers to carry not only provisions for themselves, but for their beasts of burden. Besides, the country being flat and sandy, without mountains, rivers, woods, lakes, or any other object to direct their course, it would be impossible to avoid losing their way, were it not for the flight of certain birds, who are observed to go and return at stated periods. Travellers are also guided by the course of the sun by day, and of the stars by night; and the latter is generally the time of travelling here, as well as in the deserts of Arabia. All the parts of these immense deserts are not equally inhospitable, some being inhabited by different tribes of Arabs; but the province or desert of Zuenzina is peculiarly dry and barren, and it has been asserted, that of large caravans which pass through this country, seldom one-half of the aggregate which set out, either of men or beast, ever return, numbers of them dying by thirst, hunger, fatigue, or perishing under the whirlwinds of sand which frequently overwhelm them. Through the no less dreary and dangerous desert of Lemta, caravans pass from Constantia, and other towns of Algiers and Tunis, to Nigritia, or Negroland, though equally in danger of perishing by thirst, hunger, and the sword. The most extraordinary journies are those of the akkabaahs, or accumulated caravans, from Morocco to Tomboctoo, consisting often of not less than seven hundred camels. Here the heat is intense, the sand drives in surges, and the *shumah* or burning wind carries death with every blast.

Western Coast of Africa. The countries on this coast to which Europeans chiefly resort for the purposes of commerce, and at which they procure ivory, gold dust, Guinea-pepper, and slaves, are extremely hot and unhealthy. They lie southward of the great river Senegal, in latitude 16° N. and extend quite to the line, the most considerable of which is Guinea. Here the periodical rains overflow the level part of the country, which add greatly to its unwholesomeness. It has frequently happened that European ships have lost one-half of their crews by fevers, whilst lying in this situation; but by providing better medical assistance on board

the ships, and applying the most effectual remedies, the devastations of this sultry and pestiferous climate have been greatly lessened. Tremendous storms of thunder and lightning occur often on the coast, and it is not uncommon for European seamen, when exposed to the full force of the lightning, to be struck with instant blindness by a flash.

The island of St. Thome, or St. Thomas, is somewhat of a round figure, and about one hundred and twenty miles in circumference; it is situated directly under the equator, and is between forty and fifty leagues to the westward of the continent of Africa. The heat and moisture of the air here render the island extremely unhealthy to Europeans, yet the negroes and mulattos who inhabit it are said to possess a good share of health, and frequently live to an advanced age.

Those countries which lie on the north of the line are much more intensely hot, and, on account of the periodical rains which fall, much more unhealthy, than the countries on the south of it in the same degree of latitude, such as Loango, Congola, and Angola, which are somewhat defended by eminences.

The small island of Tinian, situated in 15° 8′ N. latitude, and 146° 0′ W. longitude, is one of that cluster of islands called by Magellan, who discovered them, the *Ladrones,* and since the *Marian Islands:* its extent from east to west is about twelve miles, but from north to south it is little more than six. This small spot has been celebrated for its extraordinary beauty and fertility, and the very seasonable and effectual relief which it afforded to Commodore Anson's people, on board the Centurion, when on the point of perishing. Although at present uninhabited, the remains of pyramidical pillars, and other ruins, fully evince that it was once very populous. The Spaniards had a settlement upon it for a considerable time, which had not been long removed when the Centurion touched here.

Although the account which is given by the very able writer of Lord Anson's voyage, represents this spot as possessing all the charms of an earthly paradise, yet the island does not seem to have been equally propitious to Commodore Byron and his crew, who touched at it July 31, 1765; for although such as were languishing with the scurvy were soon recovered when removed on shore, yet many were seized with fevers, of which two died; the rains were

very violent, and almost perpetual; whilst, to increase their distress, the heat was so intense that the thermometer on board the ship generally stood at 86°, which is only twelve degrees below the heat of the blood in the human body. The sun was then almost vertical. The fishes which were caught on the coast were poisonous, and much disordered all who ate of them. The excessive heat caused whatever provision they killed to turn green, and to swarm with maggots in less than an hour after, and if a method had not been devised of snaring the wild hogs, and so procuring them alive, their subsistence would have been very scantily dealt out, but by this contrivance they were well stocked with fresh provisions: some of these wild hogs weighed two hundred pounds, and many were sent on board to furnish provisions in the prosecution of the voyage. Byron asserted, that he never felt such heat either on the coast of Guinea, in the West Indies, or upon the island of St. Thomas. So great a difference does a month seem to make in the condition of this island; for the Centurion arrived at the end of August, 1743, and in September, 1767, Captain Wallis, in the Dolphin, put in here for refreshments, and continued near a month, during which time he found every necessary accommodation, and apparently without the inconveniences of heat and rain. But although the difference of season might materially affect the state of the weather, yet it cannot be supposed to occasion so very material an alteration; there is therefore, another cause to be assigned, and which may be considered as sufficient to acquit either narrator of exaggeration in his description. For if it be considered that the Spaniards had for many years cultivated this spot when the Centurion arrived there, and that it bad been totally neglected from that time to the arrival of Byron in the Dolphin, the state of the atmosphere must necessarily have been very much changed by the wild luxuriance of nature in the course of so many years.

Batavia, the emporium of the Dutch in the East Indies, is one of the hottest and most unhealthy spots on the globe. The island of Java, on which this city is situated, lies in latitude from 5° 50′ to 8° S. The unhealthiness of the place is increased by the number of canals which have been cut for the purpose of receiving merchandise, the sides of which are planted with trees, that whilst the stagnant waters serve to raise the noxious vapours, prevent the dispersion of the vapours by obstructing the free circulation of air.

In dry weather a most horrible stench arises from these canals; and when the rains have so swelled them that they overflow their banks, the ground-floors of the houses in the lower part of the town are filled with stinking water, which leaves behind it dirt and slime in prodigious quantities. The inhabitants sometimes clean their canals, but this business is performed in such a manner as scarcely to make them less a nuisance than before, for the black mud being raked from the bottom, is left on the sides, till hard enough to be taken away in boats; and as there are no houses appropriated for necessary retirement in the whole town, the filth is thrown into the canals regularly once a day, which renders this mud a still further compound of every thing offensive and putrefactive. Farther to contaminate the air, the fence of every field and garden is a ditch, and interspersed among the cultivated grounds are many filthy fens, bogs, and morasses, as well fresh as salt. At the distance of about forty miles inland, there are hills of a considerable height, "where, as we were informed," says Captain Cook, "the air is healthy, and comparatively cool." The same situation and circumstances which render Batavia and the country round it unwholesome, render it the best garden ground in the world; the soil is fruitful beyond imagination, and the conveniences and luxuries of life which it produces are almost without number. The insalubrity of this climate is in part attributed to the bad quality of the water, therefore those who can afford it drink nothing but Seltzer water, which till of late they had from Holland at a vast expense.

The city of Batavia, till it lately yielded to British prowess, was generally supposed to be impregnable; for the roads by which heavy artillery must be brought against the town might, it was conceived, be easily destroyed, and, says Captain Cook, "if an enemy be only stopped a short time in his approach, he is effectually baffled, for the climate will destroy him without the use of any implements of war. We were informed," continues he, "that it was a very uncommon thing for fifty soldiers to be alive at the expiration of the first year, out of an hundred brought from Europe, and if one half survived, not ten of those were likely to be found in health.

The malignity of the air in that part of Asia is not confined to the island of Java, but pervades the whole Archipelago south of

the equator, of which it is a part. When the ships were returning home on the third voyage undertaken by Captain Cook, they no sooner entered the straits of Banca than the men began to experience the powerful effects of that pestilential climate. Two of the people on board the Discovery fell dangerously ill of malignant putrid fevers, which, however, were prevented from spreading by putting the patients apart from the rest, in the most airy births: many were attacked with teazing coughs, others complained of violent pains in the head, and even the most healthy felt a sensation of suffocating heat, together with an insuperable languor, and total loss of appetite.

[*Horneman. Jackson. Cook.*

CHAP. XXXVII.

DEGREES AND EFFECTS OF SEVERE COLD IN HIGH LATITUDES, OR WHERE IT HAS BEEN MINUTELY ATTENDED TO.

SECTION I.

Cold of the South Polar Regions.

WE have observed in a preceding chapter, that high southern latitudes are visited with a severer degree of cold than equal latitudes towards the north pole, and have pointed out the probable cause. Yet, whatever the cause may be, the difference is very great; thus Glasgow, in Scotland, is situated just about the same northern latitude as Cape Horn is in the southern, whilst the winters in the first are attended with a less degree of cold than many summer days in the latter. The island of Terra del Fuego, although never visited by European navigators but in the summer months, is described as amongst the most dreary and desolate spots of the habitable earth, and the few inhabitants upon it as the most

miserable and destitute of the human race. The sufferings which Sir Joseph Banks, Dr. Solander, and their company endured, when embarked with Captain Cook on board the Endeavour, on this coast, near Strait le Maire, in January 1768, which is the height of summer in that hemisphere, answering to July in the northern, prove the changeableness of the weather, and the severity of the cold.

Sir Joseph (then Mr.) Banks and Dr. Solander were desirous of availing themselves of a fine day, which, in that climate, is very rare, even at that time of the year, to explore a country which had never been visited by any botanist. For this purpose, they went on shore early in the morning, being twelve in company. They presently found great and unexpected impediments in their progress, by deep swamps and thick underwood, so that it was three o'clock in the afternoon before they could ascend a mountain of moderate height; when suddenly the air, which had been till then serene and mild, became cold and piercing, and snow began to fall; notwithstanding which, they proceeded, in expectation of reaching the rocky part of the hill, that lay before them at a small distance. Their perseverance, indeed, was rewarded by their finding a variety of undescribed plants; but the day, however, was now so far spent that it was impossible to return to the ship that night; while the cold had by this time become very intense, and such large quantities of snow had fallen, that the most dreary prospect presented itself. Whilst they were proceeding in search of the nearest valley, Dr. Solander, who was well acquainted with the effects of intense cold, having passed over the mountains that divide Sweden and Norway, represented to the company the necessity they were under of continuing in motion, however they might feel themselves attacked by a lassitude and sluggishness; and assured them, that whoever sat down would sleep, and whoever slept would wake no more!

They had not proceeded far before the effects apprehended began to be felt, and he, who had thus cautioned others, was the first to declare himself unable to observe his own precept; at length, overcome by a stupor, he threw himself on the ground, although it was covered with snow. A black servant of Mr. Banks, named Richmond, next yielded to this fatal propensity. In this distress, five of the company were sent forward to make a fire at the first

convenient place they could find, whilst the rest continued with the doctor, making use of every means to keep him awake. The poor negro was so overcome with fatigue, that being told he must keep in motion or he would be frozen to death, replied that he desired only to lie down and die! At length, all the endeavours of the company became ineffectual; their whole strength was not sufficient to carry their two exhausted companions, so that they were suffered to sit down, and in a short time they fell into a profound sleep. In a few minutes afterwards, news was brought that a fire was kindled at the distance of about a quarter of a mile. Dr. Solander was then waked with great difficulty; but during his short sleep, his muscles were become so contracted, that his shoes fell off his feet, and he had almost lost the use of his limbs; but all attempts to wake the servant were ineffectual: two men, who seemed to have suffered the least by the cold, were left to look after him, and in a short time, two others were sent to their relief; one of the former rejoined the company, but the other was quite insensible; their companions, therefore, made them a bed of boughs, and spread the same covering over them to a considerable height, and in that situation left them to their fate.

The company passed the remainder of the night in a dreadful situation, round the fire. They supposed themselves at a great distance from the ship, their way stretched through a trackless wood, and they were unprovided with refreshments, their only provisions being a vulture, which they had shot in the course of their journey. Nor did the dawn of day remove their apprehensions; for at the approach of light nothing presented itself to their view but a dreary expanse of snow. It was not till six o'clock in the morning that they could discover the place of the sun through the clouds, which then began to disperse. With foreboding apprehensions they went in search of poor Richmond and the other man, whom they found quite dead; a dog, which belonged to one of them, was, however, still alive and standing close by his master's corpse, which he unwillingly left to follow the company. The hardy nature of this animal enabled him to brave the severity of the weather, and he was for several years afterwards alive in England.

About eight o'clock the snow began to melt, and the company determined upon setting forward. Their hunger by this time be-

came outrageous; having, therefore, skinned their vulture, they divided it into ten parts, every man dressing his own share for himself. This scanty meal, which only furnished each person with a few mouthfuls, being finished, they quitted the fire-side about ten o'clock, and, no less unexpectedly than joyfully, reached the beach where the ship lay in about three hours; for upon tracing their advances toward the hill the day before, they found, that, instead of ascending in a direct line, they had almost gone round it. How much is the world indebted to men of science, who will brave all the dangers of the most inhospitable climes to enlarge the stores of human knowledge!

The next voyage which Captain Cook conducted was that in which he a second time circumnavigated the globe. The principal object of it was to explore the high southern latitudes, and to ascertain with precision how far it was possible to penetrate toward the south pole. For this purpose two ships were fitted out, the Resolution and Adventure; of the latter, Captain Furneaux had the command. In perusing the account of this most important enterprise, curiosity and astonishment are ever on the wing whilst following the daring course of British mariners over a watery expanse which no keel had ever cut before, and which may perhaps never again be traversed through all the periods of recording time. The learned reader may therefore feel himself inclined to exclaim with Horace—

> Illi robur, et æs triplex
> Circa pectus erat, qui fragilem truci
> Commisit pelago ratem
> Primus, &c.
>
> Or oak, or brass with triple fold
> Must have mortal's daring breast enroll'd,
> Who first to OCEAN's barbarous rage
> Launch'd the frail bark. FRANCIS.

Roggewein, a Dutch navigator of considerable note, had sailed so far to the southward as to approach very near to the Antarctic circle, but Captain Cook proceeded beyond it, and penetrated near five degrees farther toward the south pole. Indeed, during the voyage he three times passed the Antarctic: the first time was in the year 1773, in longitude 39° 35′ E. when he proceeded to 67° 35′ S. the second and third times were in the years 1773 and 1774,

he then crossed it in 147° 46′ west longitude (December 20th) and proceeded to about 132°, and afterwards in 109° 31′. W. (January 26th, 1774.)

In the third attempt to proceed southward, on the 25th of January, the mildest sunshine was enjoyed that had perhaps ever been experienced in the frigid zone, which led Captain Cook to entertain hopes of penetrating as far toward the south pole as other navigators had done towards the north pole; but the next day, about four in the morning, his officers discovered a solid ice-field of immense extent before them, which bore from east to west. A bed of fragments floated all round this field, which seemed to be raised several feet high above the level of the water. Whilst in this situation, the southern part of the horizon was illuminated by the rays of light reflected from the ice, to a considerable height. Ninety-seven ice-islands were distinctly seen within the field, beside those on the outside; many of them very large, and looking like a ridge of mountains, rising one above another till they were lost in the clouds. The outer, or northern edge, of this immense field, was composed of loose or broken ice close packed together, so that it was not possible for any thing to enter it. Such mountains of ice as these, Captain Cook believed were never seen in the Greenland seas, so that no comparison can be drawn between the ice here and there; and it was the opinion of most on board, that this ice extended quite to the pole, to which they were then within less than nineteen degrees; or perhaps joined to some land to which it had been fixed from the earliest time; and that it is to the south of this parallel that all the ice is formed, which is found scattered up and down to the northward, and afterward broken off by gales of wind, or other causes, and brought forward by the currents which were always found to set in that direction in high latitudes. Some penguins were heard even here, but none seen, and few other birds, or any thing that could lead to a supposition that there was any land near: however, Captain Cook conceived that there must be land to the south behind this ice. "But if there is," says he, "it can afford no better retreat for birds, or any other animals, than the ice itself, with which it must be wholly covered: I, who was ambitious, not only of going farther than any one had been before, but as far as it was possible for man to go, was not sorry at meeting with this interruption; as it in some measure relieved us, at least

shortened the dangers and hardships inseparable from the navigation of the southern polar regions. Since therefore we could not proceed further to the south, no other reason need be assigned for my tacking and standing back to the north, being at this time in the latitude of 71° 10′ south, longitude 106° 54′ west;" which was the nearest approximation to the pole during the whole voyage.

After having thus fully explored those appaling regions he bade an eternal farewell to the southern frigid zone, crossing the Antarctic at 101° west longitude.

On Christmas day 1773, the Midsummer in those parts, they were in about 58° south, and Captain Cook made this remark in his journal. "Although this was the middle of summer with us, I much question if the day was colder in any part of England. During their whole summer continuance in those latitudes, they had no thaw, for the mercury in Fahrenheit's thermometer kept generally below the freezing point.

Whilst in the frigid zone, they had scarcely any night, so that within a few minutes of midnight, the light of the sun was sufficient to write or read by. The sun's stay below the horizon was so short that a clear twilight continued all the time of his disappearing.

In the first attempt to penetrate southward, Captain Cook was one hundred and seventeen days without a sight of land, and in his second, he was one hundred and four in the same situation,

> Beating for joyless months the gloomy wave ;

and doomed all that time to explore

> Thrilling regions of thick-ribbed ice,
> And blown with restless violence round about
> The pendant world.

It might have been supposed, that the hardships and dangers which had been endured, together with the important geographical knowledge which had been acquired, would have induced this great navigator, now that he had quitted the South Sea, to rest from his labours, and to seek his native country by the most direct rout. But, like Cæsar, thinking nothing done whilst any thing remained undone, he was still intent on farther researches, and resolved to traverse the Atlantic Ocean, between the 50th and 60th degrees of latitude, from the meridian of Cape Horn to that

of the Cape of Good Hope, in which he spent upwards of three months. That the officers and men quietly acquiesced in this farther extension of their toils and perils, deprived of the two essentials to the enjoyment of life, nourishing food and human intercourse; that amidst the chaotic scenes which yet detained them, a general spirit of discontent, and a strong propensity to mutiny, did not prevail, prove their great leader to have possessed that elevation of mind and insinuating manner, which effectually controul the most boisterous spirits, and make the heaviest and the longest sufferings supportable, merely by having such a man to partake in them, and cheerfully to undergo them.

In the cruise of 1775, a large island was discovered, which our navigator named Southern Georgia. It lies between 53° 57′ and 54° 57′ south latitude, 38° 13′ and 35° 34′ west longitude, and is described as a country the most savage and horrible; not a tree nor even a shrub was to be seen; the whole rocks raised their lofty summits till they were lost in the clouds, and valleys lay covered with snow. Seals and sea bears were numerous, and a sea lion was shot. The seals and penguins killed here, were very acceptable food to the whole crew; for any kind of fresh meat was eagerly coveted. "For my own part," says Captain Cook, "I was now, for the first time, heartily tired of salt meat of every kind; and though the flesh of the penguins could scarcely vie with bullock's liver, it being fresh, was sufficient to make it go down." Even the climate of Tiero del Fuego, though lying more to the southward, is mild, with respect to that of Georgia; the difference in the thermometer being observed to be at least 10 degrees. Beside being uninhabitable, South Georgia does not appear to contain a single article for which it might be visited occasionally by European ships. Not a river or stream of fresh water was seen on the whole coast.

Captain Cook left the southern part of this island on the 26th of January, and steered east-south-east until he arrived in 60° lat. further than which he did not intend to go, unless he observed some certain signs of meeting with land. These high southern latitudes, where nothing was to be found but ice and thick fogs, had at length tired even this persevering chieftain himself. Many on board were at this time afflicted with severe rheumatic pains and colds, and some were suddenly taken with fainting fits, since their

unwholesome juiceless food could not supply the waste of animal spirits. As the ship was now proceeding northward, the hope of soon reaching a milder climate diffused a general satisfaction; but another frozen country rose to their view, and threatened to retard the accomplishment of their wishes. The discovery of this land was made on the 31st of January, at seven in the morning. Captain Cook gave the name of Sandwich-Land to this discovery, which may possibly be the northern point of a continent; for he is of opinion that there is a tract of land near the pole, which is the source of most of the ice that is spread over this vast Southern Ocean. He likewise thinks it extends farthest to the north opposite the southern Atlantic and Indian Oceans, because ice was always found more towards the north in those seas than any where else; which he imagines could not be, if there was not land of considerable extent to the south; but the risk that is run in exploring a coast in these unknown and icy seas is so very great, that he concludes, on the best grounds, that no man will ever venture farther than he has done; and that the lands which may lie to the south will never be explored. Thick fogs, snows, storms, intense cold, and every other thing that can render navigation dangerous, must be encountered, and these difficulties are greatly heightened by the inexpressibly horrid aspect of the country; a country doomed by nature never once to feel the warmth of the sun's rays, but to lie buried in everlasting snow and ice. The ports which may be on the coast are in a manner wholly filled up with frozen snow of vast thickness; and if any be so far open as to invite a ship in it, she would run a risk of being fixed there for ever, or of coming out in an ice-island. The islands and floats on the coasts, the great falls from the ice-cliffs in the port, or a heavy snow-storm, attended with a sharp frost, would be equally fatal. The most southern extremity that was seen was called *Southern Thule,* and lies in latitude 59° 30′ south, longitude 27° 30′ west. The whole country had the most desolate and horrid appearance imaginable; not a single blade of grass could be discerned upon it, and it seemed to be forsaken even by the amphibious and lumpish animals which dwell in South Georgia. It remains very doubtful whether the different projecting points form one connected land, or several distinct islands; and this may probably continue undetermined for ages, since an expedition to those inhospitable parts of the world, beside being extremely perilous, does not

seem likely to be productive of great advantages to mankind. Prudence would not permit the commander to venture near a coast subject to thick fogs, where there was no anchorage, and every part was blocked and filled up with ice, and the whole country, from the summits of the mountains down to the very brink of the cliffs which terminate the coast, was covered two fathom thick with everlasting snow.

Thron'd in his palace of cerulean ice,
Here Winter holds his unrejoicing court ;
And thro' his airy hall the loud misrule
Of driving tempest is for ever heard :
Here the grim tyrant meditates his wrath ;
Here arms his winds with all-subduing frost :
Moulds his fierce hail, and treasures up his snows.

" It would have been rashness in me," says Captain Cook, " to have risked all that had been done during the voyage in discovering and exploring a coast, which, when discovered and explored, would have answered no end whatever, or have been of the least use to navigation or geography, or indeed to any other science."

It had long been a prevailing opinion among the learned that a large continent existed in the Southern hemisphere, of which New Holland, a country which had been visited and named by Tasman, a Dutch navigator, was supposed to be a part. This imaginary continent was generally styled *Terra Australis incognita,* but such an idea is now entirely refuted, for the panegyrist of Captain Cook justly remarks, that " this voyage will immortalize the conductor of it ; in it vast tracts of new coast were not only discovered but surveyed, the illusion of a Terra Australis incognita was dispelled, whilst the bounds of the habitable earth as well as those of the navigable ocean in the southern hemisphere, were fixed."

[*Hawkesworth, Forster, Pringle.*

SECTION II.

Ice Islands, and sufferings of Lieutenant Riou and his Crew, in the Guardian Frigate, by striking against an Island of this kind.

Among the many interesting discoveries which this voyage revealed to the world, the vast islands of floating ice which abound in the southern latitudes may be considered as peculiarly worthy of notice. The first of these was met with on the 10th of December, 1773, in latitude 59° 40′ south. It was about fifty feet high, and half a mile in circuit, flat at top, while its sides rose in a perpendicular direction, against which the sea broke exceedingly high.

In the afternoon of the same day, they sailed near another large cubical mass, which was about 2000 feet long, 400 feet broad, and at least as high again as the main top gallant-mast head, or 200 feet. According to the experiments of Boyle, and Mairan, the volume of ice is to that of sea-water nearly as 10 to 9; consequently, by the known rules of hydrostatics, the volume of ice which rises above the surface of the water, is to that which sinks below it as 1 to 9. Supposing therefore this piece to be entirely of a regular figure, its depth under water must have been 1800 feet, and its whole height 2000 feet: allowing its length as above mentioned 2000 feet, and its breadth 400 feet, the whole mass must have contained 1600 millions cubic feet of ice. Such is the account given by Mr. Forster. Mr. Wales, astronomer on board the Resolution, who published "Remarks on Mr. Forster's account of this voyage," doubts the principles on which the calculation is founded, as the experiments above referred to were made with real, solid and compact ice, whereas the ice which composed this mass was light and porous, being chiefly snow and salt water-frozen together, and bears not perhaps a greater proportion to the weight of salt-water than that of 5 to 6, or 6 to 7 at the utmost.' On the 12th, six more islands were seen, some of them nearly two miles in circuit, and 60 feet high; and yet such was the force and height of the waves, that the sea broke quite over them. This exhibited for a few moments a view very pleasing to the eye, but a sense of danger soon filled the mind with horror; for had the ship got

against the weather side of one of these islands, when the sea ran high, she must have been dashed to pieces in a moment. On the 14th, their rout to the southward was stopped by an immense field of low ice, 54 deg. 50 min. south, 21 deg. 34 min. east. No end could be seen to this ice, either to the east, west, or south. In different parts of the field were islands, or hills of ice, like those that had been before found floating in the sea; several on board thought they saw land over the ice, but they were only fog-banks, which bore that appearance.

The ships then changed their course to the eastward; large islands of ice were hourly beheld in all directions round the sloops, so that they were become as familiar to those on board as the clouds and the sea. Whenever a strong reflection of white was seen on the skirts of the sky near the horizon, then ice was sure to be met with: notwithstanding which, the ice itself is not entirely white, but often tinged, especially near the surface of the sea, with a most beautiful sapphirine, or rather berylline blue, evidently reflected from the water. This blue colour sometimes appeared 20 or 30 feet above the surface, and was probably produced by some particles of sea-water which had been dashed against the mass in tempestuous weather, and had penetrated into its interstices. In great islands of ice were frequently observed shades or casts of white, lying above each other in strata, sometimes of six inches, and at other times of a foot high. This appearance seems to confirm the opinion concerning the increase and accumulation of such huge masses, by heavy falls of snow at different intervals: for snow being of various kinds, small-grained, large-grained, in light feathery locks, &c. the various degrees of its compactness account for the different colours of the strata.

Islands of ice still surrounded them, and in the evening the sun setting just behind one of them, tinged its edges with gold, and brought upon the whole mass a beautiful suffusion of purple. January 9, 1773, three boats were hoisted out, and in about five or six hours took up as much ice as yielded fifteen tons of good fresh-water. The salt-water which adhered to the ice was so trifling as not to be tasted, and after it had lain on deck a short time, entirely drained off; and the water which the ice yielded was perfectly sweet and well tasted. Part of this ice was broken in pieces, and put into casks; another part was melted in the

copper, and filled up the casks with water; and some was kept on deck for present use. This water had a purer taste than any which was on board; the only fault it possessed, according to Mr. Foster, was that the fixed air was expelled from it, by which means almost every one who used it was afflicted with swellings in the glands of the throat. Mr. Wales the astronomer, in his remarks on Mr. Forster's work, doubts whether water procured from ice causes such soreness and swellings; and asserts that disorders of these kinds were by no means general on board the Resolution. Certain it is, that the fixed air might easily have been incorporated into this fluid, only by pouring it from one vessel into another, backward and forward, for a short time. Here was a discovery made important to science; that nature forms great masses of ice in the midst of the wide ocean, which are destitute of any saline particles, but have all the useful and salubrious qualities of the pure element. "Crantz, in his History of Greenland, relates, that the stupendous masses of ice found in the northern seas, called ice-islands or mountains, melted into fresh water; though he did not imagine that they originated from the sea, but that they were first formed in the great rivers of the north, and being carried down into the ocean, were afterwards increased to that amazing height by the snow that fell upon them; but that all frozen sea-water would thaw into fresh, had either never been asserted, or had met with little credit; neither did Captain Cook expect such a transmutation."

January 31, they passed near two islands of ice 50° 50′ S. 56° 48′ E. one of which appeared to be breaking or falling into pieces, by its crackling noise, which, according to Captain Cook, was equal to the report of a four-pounder.

The second time Captain Cook crossed the antarctic circle, in longitude 147° 46′ W. ice-islands also were seen very high and rugged, forming at their tops many peaks; while those which had been seen before, were flat and not so high. Many of the latter moreover, were two and three hundred feet in height, and between two and three miles in circuit, with perpendicular cliffs or sides astonishing to behold.

The following passages which occur in Mr. Forster's account of this voyage are too interesting too be omitted here. On Christmas-day the captain invited the officers and mates to dinner; and one

of the lieutenants entertained the petty officers. "The sailors feasted on a double portion of pudding, regaling themselves with the brandy of their allowance, which they had saved for this occasion some months beforehand, having a premeditated solicitude to get drunk on that day. The sight of an immense number of ice-islands could not deter the sailors from indulging in their favourite amusement; as long as they had brandy left they would persist to keep Christmas, though the elements had conspired together for their destruction. Their long acquaintance with a seafaring life, had inured them to all kinds of perils; and their heavy labour, with the inclemencies of the weather, and other hardships, making their muscles rigid and their nerves obtuse, had communicated insensibility to their minds. Jan. 20, being in lat. 62° 34′, longitude 116° 24′ west, they were becalmed; when two ice-islands came in sight, one of which appeared to be as large as any that had been seen; it was supposed to be full two hundred feet in height, and terminated in a peak not unlike the cupola of St. Paul's church. January 25th, the wind increased very much, and in short time blew a tempestuous gale. At nine o'clock at night a huge mountainous wave struck the ship on the beam, and filled the deck with a deluge of water; it poured into the cabin, and extinguished the lights, leaving the gentlemen who were sitting there for a moment in doubt, whether they were not entirely overwhelmed, and sinking into the abyss. Indeed, the situation of those on board was at this time very dismal. The ocean about them wore a furious aspect, seeming, as it were, to be incensed at the presumption of a few intruding mortals. "A gloomy melancholy," says Mr. Forster, "loured on the brows of our shipmates, and a dreary silence reigned among us. Salt meat, our constant diet, was become loathsome to us all, even to those that had been bred to a nautical life from their earliest years. The hour of dinner was hateful to us; for the well-known smell of the victuals had no sooner reached us, than we found it impossible to partake of them with a hearty appetite." Thus were these southern cruisers beset with hardships peculiarly severe. The ice, the fog, the storms, and ruffled surface of the sea, composed a soul-sinking scene, which was seldom cheered by the reviving beams of the sun. "In short," says Mr. Forster, "we rather vegetated than lived; we withered, and became indifferent to all that animates the soul at

other times; we sacrificed our health, our feelings, our enjoyments, to the honour of pursuing a track unattempted before."

Whilst upon this subject, we ought not to pass over the sufferings of Lieutenant Riou and his crew, in the Guardian frigate, about the latitude of 45° south, and their almost miraculous escape from shipwreck, when carried against a vast ice-island, in foggy weather, proving more especially how peculiarly fortunate Captain Cook was through the whole course of his dangerous navigation.

Lieutenant Riou was proceeding to the new settlement at Botany Bay with stores and provisions, having some convicts on board. The force with which the ship struck against a mountainous ice-island on Christmas-day, 1789, then in a latitude much more to the northward than those floating islands are generally met with, had rendered her so leaky, that all the exertions of the officers and crew were ineffectual to stop its increase. When the ship was thought to be on the point of sinking, provisions and necessaries were providing for the boats, the officers and men in general being desirous of quitting the ship, and endeavouring, by means of the boats, to reach the nearest shore, which was more than four hundred leagues distant. Lieutenant Riou, however, declared his fixed determination to remain on board the ship, and perish with her. Whilst the horrors of death were thus before his eyes, he remained as calm and collected as when in a state of perfect security; he wrote a letter to the secretary of the admiralty, wherein he spoke highly of the good conduct both of the officers and men on board, recommended to the protection of the lords of the admiralty his sister and mother, as there seemed to be no possibility of his remaining many hours alive. When he had finished this letter, and delivered it to one of his officers, he ordered the boats to be hoisted out, and with the most anxious assiduity superintended their fitting out. On board the launch were fifteen persons, who, nine days after quitting the ship, when on the point of perishing through hunger, thirst, and fatigue, were taken up by a French merchant ship from the Mauritius bound to the Cape of Good Hope. Lieutenant Riou, and that part of the crew which remained with him on board the ship, thus abandoned to their fate, did not surrender themselves to hopeless despair; and their exertions to reduce the quantity of water in the ship were so judiciously directed, that they at length proved successful, the ship

was kept afloat, and although in continual danger of sinking, was brought into Table Bay on the 21st of February, 1790.

[*Crantz, Forster, Pringle.*

SECTION III.

Cold of the North Polar Regions, as ascertained by Lord Mulgrave.

Soon after the Portuguese had discovered the route to the East Indies, by doubling the Cape of Good Hope, an idea was formed of reaching that country, the productions of which were so much the object of European avidity, by a north-east passage. In the year 1527, Robert Thorne, a merchant of Bristol, addressed a paper to Henry VIII. on that subject, but his proposal was not attended to. In the reign of Queen Elizabeth, Sir Hugh Willoughby made the attempt with three ships in 1553. He proceeded to the latitude of 75° north, but being obliged to winter in Lapland, he and all his company perished miserably. Three years afterward, Captain Burroughs, afterward comptroller of the navy to Queen Elizabeth, sailed on the same design, and advanced to 78°. To him succeeded Captains Jackman and Pell, in 1580, in two ships, the latter of whom, with his ship, was never heard of. The Dutch began to pursue the same object in 1595, and successive voyages were made, all which tended rather to prove the impracticability of the scheme, than to bring forward any important discovery. In 1607, Henry Hudson was equipped by a company of London merchants, to discover a passage by the North Pole to Japan and China. He penetrated to 80° 23′, and was then stopped by the ice. Two years after, another ship was sent out by the Muscovy company of merchants of London, in which Jonas Poole went master. He made the southern part of Spitsbergen on the 16th of May, 1609; but, with his utmost endeavours, he could not advance farther than 79° 50′. In the year 1614, another voyage was undertaken, in which Baffin and Fotherby were employed, but without any success; and in the next year Fotherby, in a pinnace of twenty tons, with ten men; but in this voyage the ice prevented his getting further than in the last. John Wood, with a frigate and a pink, sailed in 1676, but returned without effecting any thing. Most of these voyages hav-

ing been fitted out by private adventurers, for the double purpose of discovery and present advantage, it was easy to suppose that the attention of the navigators had been diverted from pursuing the more remote object of those who employed them, with all the earnestness that could have been wished. "But," says Captain Phipps, "I am happy in an opportunity of doing justice to the memory of these men, which, without having traced their steps, and experienced their difficulties, it would have been impossible to have done. They appear to have encountered dangers, which at that period must have been particularly alarming from their novelty, with the greatest fortitude and perseverance; as well as to have shewn a degree of diligence and skill, not only in the ordinary and practical, but in the more scientific parts of their profession, which might have done honour to modern seamen, with all their advantages of later improvements. This, when compared with the accounts given of the state of navigation, even within these forty years, by the most eminent foreign authors, affords the most flattering and satisfactory proof of the very early existence of that decided superiority in naval affairs which has carried the power of this country to the height it has now attained."

This great point of geography was suffered to remain without farther investigation, from the year 1676 till 1773, when the Earl of Sandwich, in consequence of an application that had been made to him by the Royal Society, laid before the King, about the beginning of February, a proposal for an expedition to try how far navigation was practicable toward the North Pole, which the sovereign was pleased to direct should be immediately undertaken, with every encouragement that could countenance such an enterprize, and every assistance that could contribute to its success. The honourable Constantine John Phipps (late Lord Mulgrave) was appointed to conduct the expedition, and the Race-horse and Carcass bombs were fitted out to attend upon it; the command of the latter was given to Captain Lutwidge.

After passing the islands of Shetland, the first land made was Spitsbergen.

This coast lying in latitude 77° 59′ 11″, longitude 9° 13′ east, appears to be neither habitable nor accessible. It is formed of high barren black rocks, without the least marks of vegetation; in many places bare and pointed, in other parts covered with

snow, appearing even above the clouds. The vallies between the high cliffs were filled with snow or ice. "The prospect," says Captain Phipps, "would have suggested the idea of perpetual winter, had not the mildness of the weather, the smooth water, bright sun-shine, and constant day-light, given a cheerfulness and novelty to the whole of this striking and romantic scene." The current ran along the coast half a knot an hour, north. The height of one mountain seen here, was found to be fifteen hundred and three yards. Close to the harbour of Smeerenberg is an island, called *Amsterdam*, where the Dutch used formerly to boil their whale oil; and the remains of some conveniency erected by them for that purpose are still visible. Once they attempted to make an establishment here, and left some people to winter, who all perished; though the Dutch ships still resort to the place for the latter season of the whale fishery. It lies in 79° 44′ north, 9° 50′ 45″ east.

Captain Phipps brought the two ships to latitude 80° 31′ north, where are seven islands surrounded with ice. Captain Lutwidge of the Carcass and the master of the Racehorse ascended a mountain on one of them, from the summit of which a prospect extending ten or twelve leagues, eastern and north-eastward, presented itself; the whole view consisted of one continued plain of smooth unbroken ice, bounded only by the horizon. They also saw, stretching to the south-east, what is laid down in the Dutch charts to be islands. The weather was exceedingly fine, mild, and clear.

Mr. Israel Lyons, a very distinguished botanist and astronomer, who went out in the Racehorse, found here the head of a man, of which nothing remained but the bones; they were entire, and white as ivory; a puncture appeared on the skull, of a square form, which seemed as if made by a large nail. Mr. Lyons was in possession of this curiosity at the time of his death, which too eager a pursuit of knowledge brought on in the prime of life, to the great regret of his numerous literary friends.

The most remarkable views which these dreary regions present, are what are called *icebergs* (ice-hills), consisting of large bodies of ice, filling the vallies between the high mountains. Their face toward the sea is nearly perpendicular, and of a very lively light green colour. One was about three hundred feet high, with a

cascade of water issuing out of it. The black mountains on each side, the white snow, and green-coloured ice, composed a very beautiful and romantic picture. Large pieces frequently broke off from the icebergs, and fell with great noise into the water; one piece was observed to have floated out into the bay, and grounded in 24 fathoms; it was 50 feet high above the surface of the water, and of the same beautiful colour as the iceberg from which it had been separated.

On the 31st of July, a very fearful and unexpected catastrophe was encountered; the two ships became suddenly enclosed in the ice, in latitude 80° 37′; several islands and land to the N. E. together with the frozen sea, formed a basin, where no more than about four points were open for the ice to drift out, in case of a change of wind. The passage by which the ships had come in by the westward, became closed up, and a strong current set in to the eastward, by which they were carried still farther from their course. The labour of both the ships' companies to cut away the ice proved ineffectual; their utmost efforts for a whole day could not move the ships above three hundred yards to the westward through the ice, whilst the current had at the same time driven them far to the north-east and eastward. Appearances remaining thus threatening for four or five days, the safety of the crews seemed to be the only thing possible to accomplish. As it had been foreseen, that one or both of the ships might be sacrificed in the prosecution of the voyage, the boats for each ship were calculated, in number and size, to be fit, in any emergency, to transport the whole crew. Driven to this state of desperation, on the 6th of August the boats were hoisted out, and every method taken to render them secure and comfortable: but the next day the wind blew eastwardly, and the ships were moved about a mile to the westward. But still they were not so far west, by a great way, as when they were first beset with the ice: however, on the 9th of August, the current had visibly changed, and ran to the westward, by which both the ice and the ships had been carried considerably in that direction. On the 10th, a brisk wind at north-north-east accomplished their deliverance, and freed them from the dreadful prospect of perishing by the winter polar cold. Having found it impracticable to penetrate any farther toward the North Pole, they made for the harbour of Smeerenberg, which lies on the north-west side of Spitsbergen. In

prosecuting this voyage, the most northern point of latitude which they reached was 81° 36′, and between the latitudes of 79° 50′ and 81°, they traversed 17½° of longitude; being from 2° east, to 19° 30′ east.

The following are some of the most curious observations made during the voyage:—

On the 19th of June, by a meridian observation at midnight, the sun's lower limb 0 deg. 37 min. 30 sec. above the horizon, latitude 66° 54′ 39″ north, longitude 0° 58′ 45″ west. In latitude 67° 35′, Captain Phipps sounded with a very heavy lead the depth of seven hundred and eighty fathoms without getting ground; and by a thermometer, invented by Lord Charles Cavendish for the purpose, found the temperature of the water at that depth to be 26 degrees of Fahrenheit, the temperature of the air being 48 degrees and a half.—June 24, in latitude 73° 40′, a fire was made in the cabin for the first time.—On the 1st of July, it was found so warm, that they sat without a fire, in 78° 13′ 36″.—In 78° 0′ 50″, at four in the morning, Lord Charles Cavendish's thermometer was 31 deg. that of the air 40 deg. and a half. At two in the afternoon, at one hundred and fifteen fathoms, the water was 33 deg. at the surface 40 deg. and in the air 44¾ deg.—July 16th, the greatest height of the thermometer was 58½ deg. at eleven in the forenoon, and at midnight 57 degrees, in latitude 79° 50′, longitude 10° 2′ 30″, east.—On the 19th of August, at eleven in the evening, an appearance of dusk was observed at Smeerenberg.—On the 24th of September, stars became visible. "The sight of a star," says Captain Phipps, "was now become almost as great a phenomenon as the sun at midnight had been two months before, when we first got within the Arctic circle. The sky was in general loaded with hard white clouds, insomuch that the sun and horizon were never entirely free from them, even in the clearest weather.

Whilst upon this subject we may observe, that the first Venetians who explored the northern extremity of the European continent, were struck with the greatest astonishment at the continual appearance of the sun above the horizon, and relate that they could only distinguish day from night by the instinct of the sea-fowls, which went to roost on shore for the space of four hours. Pietro Quirino sailed in April 1431, and in January 1432 he was ship-

wrecked under the polar circle. A bright appearance near the horizon was always a herald to signify the approach of ice; and this the pilots call the blink of the ice. The same appearance was noticed on Captain Cook's voyage towards the south pole in 1773 and 1774. Dr. Irving tried the specific gravity of ice on board the Racehorse. A piece of the most dense cold ice he could find being immersed in snow water, thermometer 34 deg. 14 fifteenth parts sunk under the surface of the water. In brandy, just proof, it barely floated; in rectified spirits of wine, it fell to the bottom at once, and dissolved immediately.

The above expedition having failed in the grand object it was designed to effect, the Honourable Daines Barrington, who proposed it to the council of the Royal Society, by which it was recommended to the board of Admiralty, in order to free himself from the imputation of having planned an undertaking which was utterly impracticable, from the solid body of ice which is ever met with there, read a paper to the Royal Society in May 1774, in which he attempted to prove the practicability, of approaching to, and even reaching the north-pole. In this paper he relates the following very singular story, which was told him by Dr. Campbel: A Dr. Daillie, who lived in Racquet-court, Fleet-street, London, about the year 1745, and practised as a physician, assured Dr. Campbel, that he had been farther to the southward and the northward than perhaps any other person who ever existed. He had sailed with Roggewein, the famous Dutch navigator, who is said to have reached the latitude of 62° 30′ south, in the year 1722. He had likewise sailed, when very young, in a Dutch ship of war, sent out to superintend the Greenland fishery, when he penetrated (to the best of Dr. Campbel's recollection, who related it from memory at the distance of thirty years) as far north as latitude 88°; and he added, that the weather was warm, the sea perfectly free from ice, and rolling like the Bay of Biscay. With these favourable appearances, Daillie pressed the captain to proceed farther: but he answered, that he had already gone too far, by having neglected his station, for which he should be blamed in Holland; on which account also he would suffer no journal to be made, but returned as speedily as he could to Spitsbergen.

Nothing but the deserved estimation in which Mr. Barrington is held could preserve so palpable an imposition from the oblivion

which it merits, as the experience of two centuries is to be placed in opposition to the bare assertion of an obscure individual, who appears to have been diverting himself with the credulity of a man of letters, and to have passed himself upon him as a most extraordinary character. Mr. Barrington afterwards pursued the subject farther, and produced a variety of doubtful testimonies, concerning advances which have been made, both by English and Dutch navigators beyond the eighty-fourth degree of latitude; from which evidence he concludes, "that the Dutch seamen employed in the Greenland fishery agree with our own countrymen, in never having so much as heard of a perpetual barrier of field ice to the northward of Spitsbergen, in 80° 30′, which indeed is one of their most common latitudes for catching whales, whilst all of them suppose the sea to be generally open in those parts; and many of them proceed several degrees beyond it." [*Payne.*

SECTION IV.

Cold of the North Polar Regions as ascertained by Captain Cook during his third Voyage, together with his Discovery of a Passage from the Pacific Ocean Northward, between the Points of Asia and America, and his attempts to navigate the North Sea.

On the return of this great navigator from his second voyage, he was promoted from the rank of master and commander to that of a captain in the navy, and was assigned an honourable retreat, by being appointed one of the four captains of Greenwich Hospital, which, beside providing him with a delightful residence, has the pay of 230*l.* per annum annexed to it. Alike caressed by the great and the learned, by natives and foreigers, who all beheld him with an enthusiastic kind of veneration, in the full possession of health and spirits, being in the fifty-third year of his age, he was one of those few favoured mortals for whom extraordinary merit had obtained an immediate recompence. Those navigators who have transmitted their names with the greatest renown to future ages, have, in general, been no less remarkable for the unworthy and mortifying returns they have met with from mankind, when they have survived their perils, and seen their labours crowned with success;

but it was Captain Cook's good fortune to live in times when merit was both discerned and recompensed.

The eastern extremity of Asia, and western coast of North America, remained at this period unknown; and although a northern passage from Europe to Asia had become an early and a favourite object, after the discovery of the western hemisphere, yet no attempt had been made to reach the north sea from the Pacific Ocean. As a navigation, therefore, of this kind was not only new, but connected with the most important part of geographical knowledge which yet remained to be revealed, namely, the exact position of the extreme points of the two continents, another voyage was resolved upon, chiefly with a view to effect those important purposes; which, when effected, nothing would remain to complete the geography of the globe, but what, as the editor of Captain Cook's third voyage (the bishop of Salisbury) observes, "might justly be called the *minutiæ* of the science." The operations proposed to be pursued were so novel, so extensive, and so various, that the skill and exertions of Captain Cook were thought requisite to conduct them: he therefore relinquished the nominal command to which he had been appointed, in order to conduct an expedition which would expose him to the toils, the hardships, and the perils of a third voyage on the great Pacific Ocean, in a direction which had scarcely been attempted. To draw forth every exertion in this undertaking, an act of parliament was passed, by which the discovery of a northern passage between the Atlantic and Pacific oceans was declared to entitle the discoverer to the reward of twenty thousand pounds, which, by an act passed in 1745, had been restrained to such expeditions as should discover a passage through Hudson's Bay; and king's ships were now entitled to the reward on making such discovery, from which they had been excluded by the former act. The Resolution sloop was appointed to this service, so little injury had she sustained in her last voyage, and the Discovery, a vessel of three hundred tons, was joined in the same expedition; the command of her was given to Captain Clerke, who had been twice round the world with Captain Cook, and once with Commodore Byron. On the 11th of July, 1776, the Resolution sailed from Plymouth, and was joined by the Discovery at the Cape of Good Hope, on the 10th of November following.

The whole of the year 1777 was employed in exploring land to the southward, and in traversing the great Pacific Ocean in various directions, by which many more islands were discovered, whilst those formerly known were re-visited; on these several useful animals were landed, to provide, if possible, a breed of cattle unknown in those regions; the western coast of North America was explored, and an acquaintance with Nootka Sound first obtained. From this port the two ships sailed on the 17th of May, 1778, to the northward, in which navigation, the mouth of a very considerable river was reached, and its course traced more than seventy leagues from its entrance, being explored as high as the latitude of 61° 30′, in longitude 150° W. but its source could not be discerned, or conjectured upon. Captain Cook, in his journal, called it "the Great River," but it has since received the name of *Cook's River*, which it is likely to retain, even when its whole extent and beneficial communications are fully ascertained.

In proceeding from the mouth of Cook's River, in the direction of north-west, on the 26th of June, at half past four in the morning, the weather being so thick that nothing could be seen at the distance of an hundred yards, those on board the Resolution were alarmed at hearing the sound of breakers on their larboard bow, which led Captain Cook to cast anchor, and to call to the Discovery to do the like. A few hours after, the fog having somewhat cleared away, the danger which they had escaped appeared to have been imminent, as the ships had passed between such rocks and breakers in the dark, as our navigator would not have ventured through in a clear day; and it appeared, that the ships had gained such an anchoring place, without choice, as was equal to any which could have been obtained by the most deliberate search! Captain Cook, in his chart, distinguishes the cape near which this event happened, by the name of *Cape Providence;* and Ellis, in his narrative of this voyage, calls it "a most providential escape;" adding, "if we had stood on five minutes longer, we must, in all probability, have been on shore; or if we had varied to the right or left, we should have run the risk of being upon the rocks."

The American coast was here ascertained to form a long and narrow peninsula, which had received from Beering, the Russian navigator of those parts, the name of *Alaska*. This pro-

jecting point of the American continent had been imperfectly traced by him, and not ascertained to be part of the continent, but was now fully explored by Captain Cook; to him, indeed, mankind will be ever indebted for the knowledge acquired of that part of the world, which, until he visited it, was altogether unknown. It has been justly remarked, that "the fictions of speculative geographers in the southern hemisphere have been continent, and in the northern hemisphere seas. If Captain Cook in his second voyage annihilated imaginary southern islands, he has made amends in his third voyage, by annihilating northern seas, and filling up the vast space which has been allotted to them, with the solid contents of his new discoveries of American land, farther westward and northward than had hitherto been traced."

On the 7th of August our navigator reached the western extremity of all America hitherto known, which he named Cape Prince of Wales; it is situated in latitude 65° 46′, longitude 168° 5′ W. On the 9th, the two ships crossed the strait, for the opposite coast of Asia, which they reached the next day: the coasts of the two continents are there distant only thirteen leagues. The people who inhabit this eastern extremity of Asia are called the *Tschutski*, and were visited by Beering in 1728. This land Captain Cook considers as properly the *Tschukotski Noss*, or eastern promontory of Asia, although the promontory to which Beering gave that name is farther to the south-west. It is a peninsula of considerable height, joined to the continent by a very low, and to all appearance, narrow neck of land, in latitude 66° 6′, and longitude 169° 38′ W. Proceeding to the north-east, they regained the American shore, being now in the Arctic or North Sea; on the 17th they had reached latitude 70° 33′, when a brightness in the northern horizon appeared, like that reflected from ice, and which is commonly called "the blink;" in an hour after, a large field of ice became visible, and shortly when in latitude 70° 41′, entirely prevented the farther progress of the ships in that direction. On the 18th the two ships were close to the edge of the ice, which was as compact as a wall, and seemed at least ten or twelve feet high; farther north it appeared much higher, its surface was extremely rugged, and here and there pools of water were observed upon it. The depth of water was from seven to nine fathoms. At this time the weather, which had been hazy, cleared up a little,

and land was seen extending from S. to S. E. by E. about three or four miles distant. As the eastern extreme point of land was much encumbered with ice, Captain Cook gave it the name of *Icy Cape*, latitude 70° 29′, longitude 162° 40′. This is doubtless a continuation of the American continent. Here prodigious numbers of sea-horses were seen, lying upon the ice. The ships were then in a critical situation, being in shoal water, upon a lee shore, the main body of the ice to windward driving down upon them. On the 21st, the ice was found to cover a part of the sea which but a few days before had been clear, and to extend farther to the south than when it was first fallen in with. Captain Cook supposed that the whole body of ice was a moveable mass.

Quitting the American coast, and proceeding to the westward, the water deepened gradually to twenty-eight fathoms, which was the greatest depth found in the Arctic or North sea. In the morning of the 26th, ice was again fallen in with, latitude 69° 36′, longitude 176° W. which gave no better prospect of getting to the north in that meridian than nearer shore. Standing to the westward, in the afternoon the ships were in a manner embayed in the ice, which lay E. N. E. and W. N. W. as far each way as the eye could reach. There being little wind, Captain Cook went with the boats to examine the state of the ice, and found it to consist of loose pieces of various kinds, so closely wedged together that it was difficult to enter the outer edge with a boat, and it was as impossible for ships to enter it as if it had been so many rocks. It was all pure transparent ice, except the upper surface, which was a little porous. It appeared to be all composed of frozen snow, and to have been all formed at sea. The pieces of ice which composed the outer edge of the field were from forty or fifty yards in extent to four or five, and Captain Cook supposed the larger pieces to rise thirty feet or more above the surface of the water; and he is of opinion that the sun has very little influence in reducing these great masses of ice, as in this climate it seldom shines out longer than a few hours at a time, and often is not seen for several days together. It is the wind, or rather the waves raised by the wind, that diminish the bulk of these enormous masses, by grinding one piece against another, and by undermining and washing away those parts that lie exposed to the surge of the sea.

On the 29th land was seen, the extreme point of which was

named *Cape North,* and beyond this the ships were unable to penetrate: it lies in latitude 68° 56′, longitude 179° 9′ W. "The coast beyond it," says Captain Cook, "must take a very westerly direction; for we could see no land to the northward, although the horizon was there pretty clear."

As there was now very little probability of finding a passage into the Atlantic, and the season was so far advanced, that the frost was expected to set in, our navigator confined his attention to the obtaining some place where wood and water might be procured, and where he might employ the winter months in making such discoveries as should prove useful to geography and navigation, at the same time that he should be enabled to render his ships and their crews in a better condition to return to the north, in farther search of a passage the ensuing summer.

[*Cook's Third Voyage.*

SECTION V.

Remarks on the State of the Globe within the Arctic Circle, as it appears from the two preceding Voyages toward the North Pole.

If the result of Lord Mulgrave's voyage was unfavourable to the opinion until then entertained of the practicability of making advances in that region of ice, the voyage of Captain Cook on the opposite side of the globe was still more so, being very near eleven degrees short of the approach made by the former; and they concur in proving the impossibility of navigating in high northern latitudes. Lord Mulgrave made his nearest approach to the pole on the 31st of July; Captain Cook's greatest approximation was on the 18th of August. The latter, on the 30th of January, 1774, proceeded nearer toward the south pole by twenty-six minutes than he was capable of penetrating toward the north. It is likewise worthy of notice, how very different the arctic regions appeared to be, in many important particulars, on its opposite sides: for instance, Lord Mulgrave could find no bottom with a vast quantity of line: Captain Cook never got a greater depth of water than twenty-eight fathoms. When sailing from Europe, currents were found to set in strong in the highest latitudes which were

reached, and to be very variable; in proceeding from the points of Asia and America, no current could be observed. On one side of the globe the sky was, in general, loaded with hard, white clouds, insomuch that the sun and horizon were never entirely free from them, even in the clearest weather; on the other side, fogs prevailed to such a degree as entirely to obscure the sun, for many days in succession. The degree of cold was likewise much greater on the Asiatic than on the European side of the globe, which accounts for the expansion of the ice being so much greater in the former place.

In the year 1770, the Hudson's Bay Company directed Mr. Hearne, an officer in their service, to explore the American continent to the north-westward of their settlements, in order to ascertain whether it was practicable to reach the northern ocean over land, and how far the continent extended northward. In this laborious enterprise Mr. Hearne was employed eighteen months. He traced the continent to its termination in about 71° 20′ N. latitude, and 123° W. longitude, but the north sea which the represented itself was frozen over, except the parts about the coast, which rendered it unquestionable that no navigation was practicable upon it, and consequently all prospect of opening a communication with Asia by means of that sea will for ever vanish.

Captain Cook having thus finished his northern cruise, visited a cluster of islands between Kamtschatka and the American coast; then proceeding to a group of islands, lying within the tropic, which had been discovered by him on this voyage, and named the Sandwich Islands, on the 1st of December reached a large island in this cluster, which was called by the natives *Owhyhee,* where he proposed to procure refreshments for his people, and to repair his ships; but whilst so employed he most unfortunately lost his life, in a skirmish with the natives, on the 14th of February, 1779.

On the death of Captain Cook, the command of the expedition devolved on Captain Clerke, who removed on board the Resolution, and Lieutenant Gore, who had three times circumnavigated the globe, became captain of the Discovery. At that time Captain Clerke's health was in a rapid decline; but although his body was fast sinking to dissolution, yet his mind continued zealously intent on conducting the two ships northward, and accomplishing

those great objects of discovery which Captain Cook had purposed to attempt, and to have entered on his career in the month of May following.

The present commander proceeded to the peninsula of Kamtschatka, and entering the bay of Awatska, landed at the little town of St. Peter and St. Paul, on the last day of April. No appearance of spring had then cheered that dreary region; here he continued until the 15th of June, in which time the two ships were well victualled and watered; but such was the state of Captain Clerk's health, that neither the repose which he enjoyed in the harbour, nor a milk and vegetable diet, with which he was supplyed by the humane assistance of a kind-hearted Russian priest, named Romanoff Vereshagen, who officiated at the village of Paratounca, about sixteen miles distant from the town of St. Peter and St. Paul, could restore that excellent officer: yet, debilitated and wasted as he was, he resolved to employ the last remnant of his life in a second attempt to find out a northern passage.—So much was he inspired with the spirit of his great master and exemplar!

In this second navigation of the Arctic or North Sea, the farthest advance which the ships were capable of making was to latitude 70° 26′, and longitude of 165° 6′ W. which was fifteen minutes short of the point reached by Captain Cook the preceding year, in a direction somewhat more than two degrees to the westward of his course, and just a month earlier in the summer, being on the 18th of July. The remainder of that month was employed in navigating the sea in various directions, gradually proceeding to the southward. On the 31st, he repassed the straits which separate the two continents, and which have received the name of *Beering's Straits*. On the 18th of August the ships again entered Awatska bay, but the day before Captain Clerke breathed his last; his remains were interred on shore, and under the orders of his successor Captain Gore, on whom the chief command now devolved, an escutcheon was put up in the church of Paratounca, prepared by Mr. Webber, the landscape painter of the Resolution, with an inscription upon it, setting forth Captain Clerke's age and rank, together with the object of the expedition in which he was engaged at the time of his death. Captain King then became commander of the Discovery.

On the 9th of October Captain Gore quitted Awatska bay, and,

proceeding south-eastward, sailed along the eastern coast of Japan, whence he proceeded to Macao, in China, and passed through the straits of Banca. On the 4th of October the ships arrived safe at the Nore.

[*Cook. Fourneaux. Hawksworth.*

SECTION VI.

Effects of Cold, as observed in 1741-2, *at Prince of Wales's Fort, at Churchill's River, Hudson's Bay.*

By Captain Christopher Middleton, F. R. S.

Captain Middleton states, that the hares, rabbits, foxes and partridges of these regions in September, and the beginning of October, changed their native colour to a snowy white; and that for six months, in the severest part of the winter, he never saw any but what were all white, except some foxes of a different sort, which were grizzled, and some half red, half white.

That lakes and standing waters, which are not above ten or twelve feet deep, are frozen to the ground in winter, and the fishes in them all perish. Yet in rivers near the sea, and lakes of a greater depth than ten or twelve feet, fishes are caught all the winter, by cutting holes though the ice down to the water, and putting lines and hooks in them. But if they are to be taken with nets, they cut several holes in a straight line the length of the net, and pass the net with a stick fastened to the head line, from hole to hole, till it reaches the utmost extent; and what fishes come to these holes for air, are entangled in the net; and these fish, as soon as brought into the open air, are instantly frozen as stiff as stock-fish. The seamen freshen their salt provisions, by cutting a large hole through the ice in the stream or tide of the river, which they do at the beginning of the winter, and keep it open all that season. In this hole they put their salt meat, and the minute it is immersed under water, it becomes pliable and soft, though before its immersion it was hard frozen.

Beef, pork, mutton, and venison, that are killed at the beginning of the winter, are preserved by the frost, for six or seven months, entirely free from putrefaction, and prove tolerably good eating. Likewise geese, partridges, and other fowl, that are killed at the same time, and kept with their feathers on, and guts in, require no

other preservative but the frost to make them good wholesome eating, as long as the winter continues. All kinds of fish are preserved in the like manner.

In large lakes and rivers, the ice is sometimes broken by imprisoned vapours; and the rocks, trees, joists, and rafters of our buildings, are burst with a noise not less terrible than the firing of a great many guns together. The rocks which are split by the frost, are heaved up in great heaps, leaving large cavities behind; which may be caused by imprisoned watery vapours, that require more room, when frozen, than they occupy in their fluid state. Neither is it wonderful that the frost should be able to tear up rocks and trees, and split the beams of our houses, when we consider its great force and elasticity. If beer or water be left in mugs, cans, bottles, or copper pots, though they were put by our bed-sides, in a severe night, they are split to pieces before morning, not being able to withstand the expansive force of the inclosed ice.

The air is filled with innumerable particles of ice, very sharp and angular, and plainly perceptible to the naked eye. Captain M. several times tried to make observations of some celestial bodies, particularly the immersions of Jupiter's satellites with reflecting and refracting telescopes: but the metals and glasses, by the time he could fix them to the object, were covered a quarter of an inch thick with ice, which rendered the object indistinct, so that it is not without great difficulties that any observations can be taken.

Bottles of strong beer, brandy, strong brine, spirits of wine, set out in the open air for three or four hours, freeze to solid ice. He tried to get the sun's refraction to every degree above the horizon, with Elton's quadrant, but to no purpose, for the spirits froze almost as soon as brought into open air.

The frost is never out of the ground; how deep cannot be certain. They have dug down ten or twelve feet, and found the earth hard frozen in the two summer months; and what moisture is found five or six feet down, is white like ice. The waters or rivers near the sea, where the current of the tide flows strong, do not freeze above nine or ten feet deep.

All the water used for cooking, brewing, &c. is melted snow and ice; no spring is yet found free from freezing, though dug ever so

deep down. All waters inland are frozen fast by the beginning of October, and continue so till the middle of May.

The walls of the house they lived in are of stone, two feet thick, the windows very small, with thick wooden shutters, which are close shut eighteen hours every day in the winter. There are cellars under the house, where are put the wines, brandy, strong beer, butter, cheese, &c. Four large fires are made in great stoves, built on purpose, every day. As soon as the wood is burnt down to a coal, the tops of the chimneys are close stopped with an iron cover: this keeps the heat within the house, though at the same time the smoke makes their heads ache, and is very offensive and unwholesome; notwithstanding which, in four or five hours after the fire is out, the inside of the walls of the house and bed-places will be two or three inches thick with ice, which is every morning cut away with a hatchet. Three or four times a day they make iron shot of twenty-four pounds weight red-hot, and hang them up in the windows of the apartments. Though a good fire be in the room the major part of the twenty-four hours, yet all this will not preserve the beer, wine, ink, &c. from freezing.

For a winter dress, they make use of three pair of socks of coarse blanketing, or Duffield, for the feet, with a pair of deer-skin shoes over them; two pair of thick English stockings, and a pair of cloth stockings upon them; breeches lined with flannel; two or three English jackets, and a fur or leather gown over them; a large beaver cap, double, to come over the face and shoulders, and a cloth of blanketing under the chin; with yarn gloves, and a large pair of beaver mittens, hanging down from the shoulders before, to put the hands in, which reach up as high as the elbows; yet notwithstanding this warm cloathing, almost every day, some of the men that stir abroad, if any wind blows from the northward, are dreadfully frozen; some have their arms, hands, and face blistered and frozen in a terrible manner, the skin coming off soon after they enter a warm house, and some have lost their toes. And their confinement for the cure of these frozen parts, brings on the scurvy in a lamentable manner. Many have died of it, and few are free from that distemper. And notwithstanding all endeavours, nothing will prevent that distemper from being mortal but exercise and stirring abroad.

Coronæ and parhelia, commonly called halos and mock-suns, appear frequently about the sun and moon here. They are seen once or twice a week about the sun, and once or twice a month about the moon, for four or five months in the winter, several coronæ of different diameters appearing at the same time. Five or six parallel coronæ, concentric with the sun, are seen several times in the winter, being for the most part very bright, and always attended with parhelia or mock-suns. The parhelia are always accompanied with coronæ, if the weather be clear; and continue for several days together, from the sun's rising to his setting. These rings are of vaous colours, and about forty or fifty degrees in diameter.

The frequent appearance of these phenomena in this frozen clime seems to confirm Descartes's hypothesis, who supposes them to proceed from ice suspended in the air.

The aurora borealis is much oftener seen here than in England; seldom a night passes in the winter free from their appearance. They shine with a surprising brightness, darkening all the stars and planets, and covering the whole hemisphere: their tremulous motion from all parts, and their beauty and lustre, are much the same as in the northern parts of Scotland, Denmark, &c.

The dreadful long winters here may almost be compared to the polar parts, where the absence of the sun continues for six months; the air being perpetually chilled and frozen by the northerly winds in winter, and the cold fogs and mists obstructing the sun's beams in the short summer they have; for notwithstanding the snow and ice is then dissolved in the low-lands and plains, yet the mountains are perpetually covered with snow, and incredible large bodies of ice continue in the adjacent seas. When the wind blows from the southern parts, the air is tolerably warm; but very cold when it comes from the northward; and it seldom blows otherwise than between the north-east and north-west, except in the two summer months, when they have light gales between the east and the north, and calms.

The northerly winds being so extremely cold, is owing to the neighbourhood of high mountains, whose tops are perpetually covered with snow, which exceedingly chills the air passing over them. The fogs and mists, brought here from the polar parts in winter, appear visible to the naked eye in innumerable icicles, as

small as fine hairs or threads, and pointed as sharp as needles. These icicles lodge in the cloaths; and if the faces or hands be uncoveréd, they presently raise blisters as white as a linen cloth, and as hard as horn. Yet if they immediately turn their backs to the weather, and can bear a hand out of the mitten, and with it rub the blistered part for a small time, they sometimes bring the skin to its former state: if not, they make the best of their way to a fire, and get warm water, with which they bathe it, and so dissipate the humours raised by the frozen air, otherwise the skin would be off in a short time, with much hot, serous, watery matter coming from under along with the skin; and this happens to some almost every time they go abroad for five or six months in the winter, so extremely cold is the air when the wind blows any thing strong.

It is observed, that when it has been extreme hard frost by the thermometer, and little or no wind that day, the cold has not near so sensibly affected them, as when the thermometer has shewed much less freezing, having a brisk gale of northerly wind at the same time. This difference may perhaps be occasioned by those sharp-pointed icicles before-mentioned striking more forcibly in a windy day than in calm weather, thereby penetrating the naked skin, or parts but thinly covered, and causing an acute sensation of pain or cold. And the same reason will probably hold good in other places.

It is not a little surprising to many, that such extreme cold should be felt in these parts of America, more than in places of the same latitude on the coast of Norway; but the difference seems to be occasioned by wind blowing constantly here, for seven months in the twelve, between the north-east and north-west, and passing over a large tract of land, and the exceedingly high mountains, &c. Whereas at Drontheim in Norway, as Captain M. observed some years ago in wintering there, the wind all the winter comes from the north-north-west, and crosses a great part of the ocean clear of those large bodies of ice found here perpetually. At this place they have constantly every year nine months frost and snow, and insufferable cold from October till the beginning of May. In the long winter, as the air becomes less ponderous towards the polar parts, and nearer to an equilibrium, as it happens about one day in a week, they then have calms and light airs all round the compass, continuing sometimes twenty-four hours, and then back to its old

place again, in the same manner as it happens every night in the West Indies, near some of the islands.

The snow that falls here is as fine as dust, but never any hail, except at the beginning and end of winter. Almost every full and change of the moon, very hard gales from the north. The constant trade-winds in these northern parts he thinks undoubtedly to proceed from the same principle which Dr. Halley conceives to be the cause of the trade-winds near the equator, and their variations. For that the cold dense air, by reason of its great gravity, continually presses from the polar parts towards the equator, where the air is more rarefied, to preserve an equilibrium or balance of the atmosphere, is very evident from the wind in those frozen regions blowing from the north and north-west, from the beginning of October till May; for when the sun, at the beginning of June, has warmed those countries to the northward, then the south-east, east and variable winds, continue till October again; and doubtless the trade-winds and hard gales may be found in the southern polar parts to blow towards the equator, when the sun is in the northern signs, from the same principle.

The limit of these winds from the polar parts, towards the equator, is seldom known to reach beyond the 30th degree of latitude; and the nearer they approach to that limit, the shorter is the continuance of those winds. In New England it blows from the north near four months in the winter; at Canada, about five months; at the Dane's settlement in Davis's Straits, in the 63d degree of latitude, near seven months; on the coast of Norway, in 64°, not above five months and a half, because blowing over a great part of the ocean, as before mentioned; for those northerly winds continue a longer or shorter time, as the air is more or less rarefied, which may very probably be altered several degrees, by the nature of the soil, and the situation of the adjoining continents.

The vast bodies of ice met with in the passage from England to Hudson's bay, are very surprising, not only as to quantity, but magnitude, and as unaccountable how they are formed of so great a bulk, some of them being immersed 100 fathom or more under the surface of the ocean; and a fifth or sixth part above, and three or four miles in circumference. Some hundreds of these are sometimes seen in a voyage, all in sight at once, when the weather is clear. Some of them are frequently seen on the coasts and banks

of Newfoundland and New England, though much diminished. When becalmed in Hudson's straits for three or four tides together, Capt. M. has taken a boat, and laid close to the side of one of them, sounded, and found 100 fathom water all round it. The tide flows here above four fathom; and he has observed, by marks on a body of ice, the tide to rise and fall that difference, which was a certainty of its being aground. And in a harbour in the island of Resolution, where he continued four days, three of these isles of ice came aground. He sounded along by the side of one of them, quite round it, and found thirty-two fathoms water, and the height above the surface but ten yards; another was twenty-eight fathoms under, and the perpendicular height but nine yards above the water.

Captain Middleton accounts for the aggregation of such large bodies of ice in this manner: all along the coasts of Davis's straits, both sides of Baffin's bay, Hudson's straits, Anticosh, or Labradore, the land is very high and bold, and 100 fathoms, or more, close to the shore. These shores have many inlets or fuirs, the cavities of which are filled up with ice and snow, by the almost perpetual winters there, and frozen to the ground, increasing for four, five, or seven years, till a kind of deluge or land-flood, which commonly happens in that space of time throughout those parts, breaks them loose, and launches them into the straits or ocean, where they are driven about by the variable winds and currents in the months of June, July, and August, rather increasing than diminishing in bulk, being surrounded, except in four or five points of the compass, with smaller ice for many hundred leagues, and land covered all the year with snow, the weather being extremely cold, for the most part, in those summer months. The smaller ice that almost fills the straits and bays, and covers many leagues out into the ocean along the coast, is from four to ten fathoms thick, and chills the air to that degree, that there is a constant increase to the large isles by the sea's washing against them, and the perpetual wet fogs, like small rain, freezing as they settle on the ice; and their being so deeply immersed under water, and such a small part above, prevents the winds having much power to move them; for though it blows from the north-west quarter near nine months in twelve, and consequently those isles are driven towards a warmer climate, yet the progressive motion is so slow, that it must take up many years before they can get five or six hundred leagues to the

southward; probably some hundreds of years are required; for they cannot well dissolve before they come between the 50th and 40th degree of latitude, where the height of the sun consuming the upper parts, they lighten and waste in time; yet there is a perpetual supply from the northern parts.

[*Phil. Trans. Abr.* 1742.

SECTION VII.

Extraordinary Degree of Cold at Glasgow, in January 1780; *with Experiments and Observations on the Comparative Temperature of the Hoar-frost and Air near it, made at Macfarlane Observatory belonging to the College.*

By Patrick Wilson, M. A.

On Tuesday, January 11, 1780, there was a slight frost, and, on the evening of that day, a fall of snow to the depth of twelve inches. Next day the cold continued to increase, but so gradually, that at sun-set Fahrenheit's thermometer pointed only to 22°.— About midnight, a very accurate thermometer, hung out at a high north window, soon after pointed to 6°. At this time the air was very still and serene, and the barometer stood at 30 inches.

Thursday morning, January 13, thermometer pointed as here annexed:

At 1 o'clock	+6°
$1\frac{3}{4}$	+6
$2\frac{1}{2}$	+4
2	+6
4	+3
$4\frac{1}{2}$	+2
5	+2
$5\frac{1}{2}$	+0

At six o'clock this morning Mr. W. carried the thermometer over to the Observatory Park, and there laid it down on the snow, when the mercury sunk to 13° below 0.

At this time he thought it unnecessary to stay abroad so long in the cold as to try the temperature of the air by hanging up the thermometers, especially as he imagined that this had been done more readily, and as truly, by taking the degree from the surface of the snow which had been exposed to the open air during the night: but reflecting afterwards on the snow at the observatory being so much below 0, the greatest cold of the air at the college, and having on other occasions found a difference of only 4° at most in air at these two stations, Mr. W. was led into a suspicion that the snow might

perhaps have been so far cooled down by an evaporation at the surface. With a view to this opinion, he projected the experiment with the bellows described below, by which he was not without expectations of producing a still more remarkable fall of the thermometer when lying on the snow. All the afternoon the cold was very intense, and at seven o'clock at night the thermometer at the high north window pointed to 0. At eight Mr. W. repaired to the observatory, and made choice of a station at a sufficient distance from the house, and to the windward, as a light air was felt coming from the east. Here he laid down two thermometers on the snow with their balls half immersed, and hung up other two freely exposed to the air at two feet and a half above the surface. In the following observations, the interruption of the series from 2½ to 6½ o'clock, was owing to an accident having befallen one of the thermometers while the other was employed in the trials, of which an account is subjoined.

Thursday evening, January 13, the two thermometers pointed at the degrees below 0, as in the following table, at the times annexed.

Exper. 1. At half past one o'clock, when the thermometer pointed to—22°, the snow contiguous to the ball was blown on for two minutes by a pair of hand-bellows, held with the pipe nearly horizontal, and half a foot above the surface of the snow. The bellows had been lying out on the snow to cool from the time Mr. W. first came over; and, in order to promote their cooling, they were now and then wrought in the open air. Care was also taken to stand to leeward of the thermometer, and to extend the bellows as far as possible from the body in the time of blowing. He was surprized to find however, notwithstanding all precautions,

At Night.	Therm. on the snow.	Therm. in the air.
8½	— 12°	— 0°
9	— 14	— 2
10	— 14	— 4
11	— 17	— 6
11½	— 18	— 6
Friday morn.		
½	— 20	— 8
1	— 23	— 7
1½	— 22	— 8
2	— 22	— 9
2½	— 21	— 8
3	—	— 9
3½	—	— 10
4	—	— 12
4½	—	— 12
5	—	— 12
5½	—	— 12

that the thermometer at the end of the experiment had got up no less than 10°, for it now pointed only to—12°. In this experiment the nozzle of the bellows was held about six inches from the thermometer, but the blast, though moderate, frequently drifted away the snow from the ball.

6	—	— 14
$6\frac{1}{2}$	— 22	— 13
7	— 22	— 13
$7\frac{1}{2}$	— 22	— 13
8	— 19	— 10

Exper. 2. At half past two o'clock, a bread-basket was filled with snow, taken up near the ground at + 14°. The contents being relatively so warm, the basket was placed to leeward of the common station, and the thermometer laid on the surface of this snow. At the several hours in the morning, the thermometer on the basket pointed as annexed, viz.

At 3^h	— 10°
$3\frac{1}{2}$	— 15
4	— $16\frac{1}{2}$
$4\frac{1}{2}$	— 18
5	— 18
$5\frac{1}{2}$	— 18
6	— 18

Exper. 3. At four in the morning, when the thermometer in the basket had got down to—16°, a piece of thin fir plank about a foot square was laid on the snow, on which was placed a small plate of tin which accidentally lay at hand. On this was laid one of the thermometers which had been hanging in the air. At the several times it pointed as annexed.

At 5	— 1
$5\frac{1}{2}$	— 16
6	— 18

During the whole time not a cloud was perceivable, but there was a faint haze in the air when viewed towards the horizon. There was little or no tremor in the atmosphere, which made the stars shine with a full and steady light like that of the planets. Many of the town's people, who had thermometers hung out at their windows, in different parts of the town, found them pointed several degrees below 0 at nine o'clock in the morning. On the afternoon of this day, January 14, the air became much warmer, and the barometer had now fallen 4-10ths. Next day a thaw came on, and continued for some time.

As the above experiment with the bellows favoured so little the opinion, that the difference of temperature was caused by evaporation, Mr. W. wished for another opportunity of making further experiments, and of inquiring into circumstances still more attentively.

A good occasion offered on Saturday, January 22. The frost, which before this time had again returned, became on this night very keen; and a good deal of the former snow yet remaining on the ground, the following observations and experiments were made at the observatory, viz. on Sunday morning, January 23: at the several hours the two thermometers pointed as in the annexed table.

Morn.	Therm. on the snow.	Therm. in the air.
$\frac{1}{2}^{h}$	+ 4	+ 14
$\frac{3}{4}$	+ 5	+ 14
$1\frac{1}{4}$	+ 4	+ 11
$1\frac{3}{4}$	+ 3	+ 11
$2\frac{1}{4}$	+ 3	+ 11
$2\frac{3}{4}$	+ 3	+ 11
$3\frac{1}{2}$	+ 1	+ 8
4	+ 1	+ 6
$4\frac{1}{2}$	0	+ 6
5	1	+ 5
$5\frac{1}{2}$	+ 1	+ 6
$6\frac{1}{4}$	— 1	+ 6
7	— 0	+ 6
$7\frac{1}{2}$	— 3	+ 5
$7\frac{3}{4}$	— 2	+ 5
$8\frac{1}{2}$	+ 1	+ 7

Exper. 4. This night, instead of blowing on the snow, Mr. W. fanned it by means of a sheet of brown paper fitted to the end of a long slender stick. This apparatus was previously cooled by lying on the snow, and in fanning he took care to stand to leeward of the thermometer. The effect was, that the mercury rose nearly to the same degree given by the thermometer in air at the same time.

Exper. 5. At $\frac{3}{4}$ past one o'clock, when the thermometer on the snow pointed to $+ 3^{\circ}$, it was screened by two sheets of brown paper set up on their edges, and so inclined against each other as to stand. The paper had been previously cooled by lying on the snow. At $2\frac{1}{4}$ the thermometer thus sheltered pointed to $+ 9^{\circ}$. This experiment was afterwards repeated with the same event.

Exper. 6. Mr. W. next went up to the leads of the east wing of the observatory. Here he hung up a thermometer to the hook of a long pole, and raised it in the air about twenty-four feet from the ground, and at the same time inclined the pole over the balustrade, so as to put the instrument fully to windward of the house. On suddenly lowering the pole, after half an hour, and examining the

thermometer, the air at that elevation was found to be pretty constantly 4° warmer than at the station below.

Exper. 7. The result of this trial appeared more remarkable than any thing which had hitherto occurred. Mr. W. lowered the pole till the thermometer was brought down within half a foot of the balustrade, but keeping it still a few inches to windward of the buildings; and by this means it was found that the air here was never cold than + 10°. On the balustrade there happened to be several detached bodies which had attracted a very thick hoar-frost. When the thermometer was taken off the hook of the pole, and laid on this hoar-frost, there was always a remarkable fall of the mercury, not less than 6°. In shifting the instrument from the pole to the balustrade, it was commonly laid on some hoar-frost $\frac{3}{4}$ of an inch deep, which had settled on a piece of thin board which had been for years exposed to the weather. Some fragments of the hoar-frost were also made to touch the upper part of the ball; which was done by pushing them on with a long frozen straw.

Exper. 8. When the thermometer, taken from the pole as in last experiment, was laid on pieces of stone, from which the hoar-frost had been brushed away for some time before, the mercury sunk but very little by such a change of situation. Next night, being that of Sunday January 23, the thermometers were placed in their former station below, when they pointed as annexed.

At Night.	Therm. on the Snow.	Therm. in the Air.
9	+ 5	+ 6
$9\frac{1}{2}$	+ 5	+ 8
10	+ 6	+ 8
$10\frac{1}{2}$	+ 6	+ 10
11	+ 6	+ 9
$11\frac{1}{2}$	+ 5	+ 8
12	+ 5	+ 8
$12\frac{1}{2}$	+ 4	+ 7
1 M^{ng}	+ 4	+ 8
$1\frac{1}{2}$ —	+ 4	+ 8

From these observations it appears, that the cold now was very moderate when compared to that of the 14th, and somewhat more moderate than that of the preceding night. Experiment 7th was again repeated with a similar result, though the difference of temperature was not now so great. This night Mr. W. made another experiment with a view to the evaporation, not so liable to objections as those of the bellows and the fan, as follows:—

Exper. 9. When the thermometer in air at the lower station had contracted a considerable film of frozen matter all over the

ball, it was swung round at the end of a pack-thread, about a yard and a half long. On stopping the motion at the expiration of two minutes, and making the servant who waited approach quickly with a lighted candle, he found the mercury had got up 2°. In this experiment, which was repeated four times with the same result, care was always taken to keep the instrument to windward of their bodies, and of the lighted candle.

The two following experiments afford some grounds for believing that no kind of evaporation was going on at the time the remarkable excess of cold in the snow and hard frost was observed :—

Exper. 10. On Sunday morning, January 23, before one o'clock, Mr. W. repeated the experiment with the metal speculum which was tried here in 1768. A large spare metal of a 2-feet telescope was laid out to cool, after which a film of ice was imparted to its polished surface, by breathing on it four or five times. It was then exposed as before, and in half an hour the whole film disappeared in the way of evaporation. But when the experiment was again repeated, and a thicker film imparted, some of this, towards the middle of the speculum, remained fixed, and would not go off after long exposure. The speculum was next warmed, and its polished surface made quite clean, and then laid out for two hours and a half. Before the expiration of this time, it began to draw frozen matter from the air, which settled all over the polished surface, in long parallel lines, which gradually multiplied, till at length it was mostly covered by a thin film resembling a spider's web.

The evaporation shewn in the first part of this experiment was probably owing to the speculum not having been sufficiently cooled when the film was first communicated to it from the lungs, and to its being further heated by that very operation. In the 2d part of the experiment, the evaporation seems to have stopped when the heat in the metal which favoured the process was exhausted; that is, when the speculum had arrived at the temperature of the ambient air; for, after that, no heat could pass from the metal in order to contribute to the evaporation. But, from the last part of the experiment, the true disposition of the air at that time, relative to bodies as cold or colder than itself, seems to be determined, namely, that of giving out or depositing hoar-frost.

Exper. 11. On Sunday night, January 23, several things were laid out at the observatory, such as sheets of brown paper, pieces

of boards, plates of metal, glasses of several kinds, &c. which all began to contract hoar-frost seemingly as soon as each body had time to cool down to the temperature of the air. The sheets of brown paper, being so thin, acquired it soonest, and when beheld in candle-light they became beautifully spangled over by innumerable reflections from the small crystals of hoar-frost which had parted from the air. Evident symptoms of the same tendency of the air to deposit, occurred on all the former nights of observing, by which the tubes of the thermometers were so much stained, that it required some attention to keep that part which corresponded to the scale quite clear.

These experiments indeed rather favour the opinion of the excess of cold, at present treated of, depending on a principle the very reverse of evaporation. But till opportunities offer in this, or in a colder climate, of making more experiments, it will be too early to say any thing decisive concerning the nature or extent of a cooling process, which has so recently come under observation. All that can at present be affirmed is, that in certain circumstances such a process goes on, and that it depends probably on principles different from evaporation or chemical solution. At the same time some of the experiments show that a free communication between the hoar-frost and external air, perhaps while in motion, is necessary; but in what manner this promotes the refrigeration does not as yet appear.

It would be going too far, were we to conclude, from the experiments related above, " that very cold air is never disposed to deposit its contents except on bodies as cold or colder than itself." And yet that this is frequently the case seems probable from a number of common appearances. We often find, after a night of frost, the slates and other thinner parts about a house whitened with hoar-frost, when the walls and more solid parts of the building remain quite free. In like manner the smaller branches and twigs of trees often acquire this frozen ornament, when the main branches and trunk remain naked for a long time; and, in general, any thin or detached body, capable of being easily cooled, attaches hoar-frost the soonest.

In favour of this general position, the following remarkable case lately occurred. Between the public library and the buildings of the new court, there is a long rail composed of bars of cast iron,

but divided into two parts by two massy stone pillars, which support the iron gate-way that leads into the garden. The bars are about six feet high, and an inch square, and fastened with lead into a stone parapet below in the usual way. A few bars much larger are set in among the rest at regular distances, to give the rail more stability. On Sunday morning, February 13, when there was a slight frost accompanied with a fog, it was entertaining to observe how the hoar-frost had settled during the night on these bars. Very little was to be seen on the flat sides, but a great deal on the angles, by which means from the top downward every bar was garnished with four fringes, which made the whole rail look very gay and ornamental. Running the eye along the foot of the bars near the parapet, it was observed, that the fringe of hoar-frost on the corners stopped short about twelve inches from the bottom, and that so much of every bar was entirely free. Two bars next the house and two next the library were likewise perfectly clear of it from top to bottom. One bar next the pillar of the gate was quite free, and the second had contracted but little. The same thing precisely may be said of the two bars contiguous to the other pillar. And it was also observed, that the few thicker and stronger bars was less fringed at the corners and were quite free much farther above the parapet than the others.

It is manifest, that during the night the air surrounding the bars must have been constantly endeavouring to make them as cold as itself: while they on the other hand, resisted this change by drawing heat from every neighbouring source which offered it, namely, from the parapet, from the pillars in the middle, and from the pillars at both ends immediate adjoining the library, and to the house in the new court: for these bodies, from their great bulk, must have been but very little cooled in the course of the night. Where-ever the air seems to have got the better in this struggle, as at the angles of the bars, which evidently must be the parts the soonest cooled, there we find that the hoar-frost was deposited, but no where else.

Several other instances were found quite of the same kind with that of the rail. Among the rest, a figure of a unicorn in the stone, which stands within the college, had resisted the attacks of the air all to the tip of his horn, which accordingly was the only part distinguished by a patch of hoar-frost. Besides this kind of

hoar-frost which joined itself to bodies by a regular arrangement, there was some of a different sort found on the uppermost surface of such bodies as were fully exposed to the open air. But this always lay scattered like very thin flakes of meal, or hair-powder, and was found to proceed from minute parts, mostly columnar, previously formed in the air, falling down by their own gravity.

[*Phil. Trans. Abr. Vol.* xiv.

CHAP. XXXVIII.

EVAPORATION.

We found reason to conclude, in the preceding chapter, that the water of the atmosphere exists in the state of *vapour*. We are indebted to the experiments of Saussure and Deluc for much of our knowledge of the qualities of vapour. It is an elastic invisible fluid like common air, but lighter; being to common air of the same elasticity, according to Saussure, as 10 to 14, or, according to Kirwan, as 10 to 12. It cannot pass beyond a certain maximum of density, without a corresponding increase of temperature, otherwise the particles of water which compose it unite together, and form small visible particles, called *versicular vapour ;* which is of the same specific gravity with atmospherical air. It is of this vapour that clouds and fogs are composed. This maximum increases with the temperature; and at the heat of boiling water is so great, that steam can resist the whole pressure of the air, and exist in the atmosphere in any quantity.

We have seen formerly, that when water is heated to 212°, it boils, and is rapidly converted into steam; and that the same change takes place in much lower temperatures; but in that case the evaporation is slower, and the elasticity of the steam is smaller. As a very considerable proportion of the earth's surface is covered with water, and as this water is constantly evaporating and mixing with the atmosphere, in the state of vapour, a precise determination of the rate of evaporation must be of great importance in meteorology. Accordingly many experiments have been made to

determine the point by different philosophers. No person has succeeded so completely as Mr. Dalton. But many curious particulars had been previously ascertained by the labours of Richman, Lambert, Wallerius, Leidenfrost, Watson, Saussure, Deluc, Kirwan, and others.

1. The evaporation is confined entirely to the surface of the water: hence it is in all cases proportional to the surface of the water exposed to the atmosphere. Much more vapour of course rises in maritime countries, or those interspersed with lakes, than in inland countries.

2. Much more vapour rises during hot weather than during cold weather. Hence, the quantity evaporated depends in some measure upon temperature. The precise law has been happily discovered by Mr. Dalton. This philosopher took a cylindrical vessel of tin, whose diameter was $3\frac{1}{4}$ inches, and its depth $2\frac{1}{2}$ inches; filled it with water, and kept it just boiling for some time. The loss of weight in the minute was 30 grains, when the experiment was made in a close room without any draught of air; 35 grains when the vessel was placed over fire in the usual fireplace, there being a moderate draught of air, and the room close; 40 with a brisker fire, and a stronger draught; and when the draught was very strong, he supposes the evaporation might amount to 60 grains in the minute. At the temperature of 180°, the quantity evaporated was $\frac{1}{2}$ of what was lost at 212°.

At 164 it was $\frac{1}{3}$ of that at 212°.
152.........$\frac{1}{4}$
144.........$\frac{1}{5}$
138.........$\frac{1}{6}$

And in general the quantity evaporated from a given surface of water *per* minute at any temperature, is to the quantity evaporated from the same surface at 212°, as the force of vapour at the first temperature is to the force of vapour at 212°. Hence, in order to discover the quantity which will be lost by evaporation from water of a given temperature, we have only to ascertain the force of vapour at that temperature. And by such examination we shall see that the presence of atmospheric air obstructs the evaporation of water; but this resistance is overcome in proportion to the force of the vapour.

3. The quantity of vapour which rises from water, even when the temperature is the same, varies according to circumstances.

It is least of all in calm weather, greater when a breeze blows, and greatest of all with a strong wind. The following Table, drawn up by Mr. Dalton, shows the quantity of vapour raised from a circular surface of six inches in diameter in atmospheric temperatures. The first column expresses the temperature; the second, the corresponding force of vapour; the other three columns give the number of grains of water that would be evaporated from a surface of six inches in diameter in the respective temperatures, on the supposition of there being previously no aqueous vapour in the atmosphere. These columns present the extremes and the mean of evaporation likely to be noticed, or nearly such; for the first is calculated upon the supposition of 35 grains loss *per* minute from the vessel of $3\frac{1}{4}$ inches in diameter; the second 45, and the third 55 grains *per* minute*.

Temperature.	Force of Vap. in Inch.	Evaporating Force in Grains.		
212°	30	120	154	189
20	·129	.52	·67	·82
21	·134	.54	.69	·85
22	·139	·56	·71	·88
23	·144	·58	·73	·91
24	·150	·60	·77	·94
25	·156	·62	·79	·97
26	·162	·65	·82	1·02
27	·168	·67	·86	1·05
28	·174	·70	·90	1·10
29	·180	·72	·93	1·13
30	·186	·74	·95	1·17
31	·193	·77	·99	1·21
32	·200	·80	1·03	1·26
33	·207	·83	1·07	1·30
34	·214	·86	1·11	1·35
35	·221	·89	1·14	1·39
36	·229	·92	1·18	1·45
37	·237	·95	1·22	1·49
38	·245	·98	1·26	1·54
39	·254	1·02	1·31	1·60
40	·263	1·05	1·35	1.65
41	·273	1.09	1·40	1·71
42	·283	1.13	1·45	1·78

* Manchester Memoirs, v. 584.

Temperature.	Force of Vap. in Inch.	Evaporating Force in Grains.		
212°	30	120	154	189
43	·294	1·18	1·51	1·85
44	·305	1·22	1·57	1·92
45	·316	1·26	1·62	1·99
46	·327	1·31	1·68	2·06
47	·339	1·36	1·75	2·13
48	·351	1·40	1·80	2·20
49	·363	1·45	1·86	2·28
50	·375	1·50	1·92	2·36
51	·388	1·55	1·99	2·44
52	·401	1·60	2·06	2·51
53	·415	1·66	2·13	2·61
54	·429	1·71	2·20	2·69
55	·443	1·77	2·28	2·78
56	·458	1·83	2·35	2·88
57	·474	1·90	2·43	2·98
58	·490	1·96	2·52	3·08
59	·507	2·03	2·61	3·19
60	·524	2·10	2·70	3·30
61	·542	2·17	2·79	3·41
62	·560	2·24	2·88	3·52
63	·578	2·31	2·97	3·63
64	·579	2·39	3·07	3·76
65	·616	2·46	3·16	3·87
66	·635	2·54	3·27	3·99
67	·655	2·62	3·37	4·12
68	·676	2·70	3·47	4·24
69	·698	2·79	3·59	4·38
70	·721	2·88	3·70	4·53
71	·745	2·98	3·83	4·68
72	·770	3·08	3·96	4·84
73	·796	3·18	4·09	5·00
74	·823	3·29	4·23	5·17
75	·851	3·40	4·37	5·34
76	·880	3·52	4·52	5·53
77	·910	3·65	4·68	5·72
78	·940	3·76	4·83	5·91
79	·971	3·88	4·99	6·10
80	1·00	4·00	5·14	6·29
81	1·04	4·16	5·35	6·54
82	1·07	4·28	5·50	6·73
83	1·10	4·40	5·66	6·91
84	1·14	4·56	5·86	7·17
85	1·17	4·68	6·07	7·46

4. Such is the quantity of vapour which would rise in different circumstances on the supposition that no vapour previously existed in the atmosphere. But this is a supposition which can never be admitted, as the atmosphere is in no case totally free from vapour. It has been shown in what manner the force of the vapour, existing in the atmosphere, may be detected by the use of Mr. Dalton's very simple apparatus. Now when we wish to ascertain the rate at which evaporation is going on, we have only to find the force of the vapour already in the atmosphere, and subtract it from the force of vapour at the given temperature. The remainder gives us the actual force of evaporation; from which, by the Table, we readily find the rate of evaporation. Thus, suppose we wish to know the rate of evaporation at the temperature 59°. From the Table we see that the force of vapour at 59° is 0·5, or $\frac{1}{60}$th its force at 212°. Suppose we find by trials that the force of the vapour already existing in the atmosphere is 0·25, or the half of $\frac{1}{60}$th. To ascertain the rate of evaporation, we must subtract the 0·25 from 0·5; the remainder 0·25 gives us the force of evaporation required; which is precisely one-half of what it would be if no vapour had previously existed in the atmosphere.

By the Table we see, that on that supposition a surface of six inches diameter would lose one grain by evaporation per minute, instead of two grains, which would have been converted into vapour if no vapour had previously existed in the atmosphere. If the force of the vapour in the atmosphere had amounted to 0·5, which is equal to the force of vapour at the temperature of 59°, in that case no vapour whatever would rise from the water: and if the force of the vapour already in the atmosphere exceeded 0·5, instead of evaporation, moisture would be deposited on the surface of the water.

These general observations, for all of which we are indebted to Mr. Dalton, account in a satisfactory manner for most of the anomalies which had puzzled preceding philosophers; and include under them the less general laws which they had discovered. We must consider the discoveries of Mr. Dalton as the most important additions made to the science of meteorology for these many years.

5. As the force of the vapour actually in the atmosphere is seldom equal to the force of vapour of the temperature of the

atmosphere, evaporation, with a few exceptions, may be considered as constantly going on.

Various attempts have been made to ascertain the quantity evaporated in the course of a year; but the difficulty of the problem is so great, that we can expect only an approximation toward a solution. From the experiments of Dr. Dobson of Liverpool, in the years 1772, 1773, 1774, and 1775, it appears, that the mean annual evaporation from the surface of water amounted to 36·78 inches*. The proportion for every month was the following:

	Inches.		Inches.
January	1·50	July	5·11
February	1·77	August	5·01
March	2·64	September	3·18
April	3·30	October	2·51
May	4·34	November	1·51
June	4·41	December	1·49

Mr. Dalton found the evaporation from the surface of water, in one of the driest and hottest days of summer, rather more than 0·2 of an inch.

If we believe Mr. Williams, the evaporation from the surface of land, covered with trees and other vegetables, is one-third greater than from the surface of water; but this has not been confirmed by other philosophers. From his experiments † it appears, that in Bradford, in New England, the evaporation during 1772 amounted to 42·65 inches. But from the way that his experiments were conducted, the amount was probably too great.

From an experiment of Dr. Watson, made on the 2d of June, 1779, after a month's drought, it appears that the evaporation, from a square inch of a grass plat, amounted to 1·2 grains in an hour, or 28·8 grains in 24 hours, which is 0·061 of an inch. In another experiment after there had been no rain for a week, the heat of the earth being 110°, the evaporation was found almost twice as great, or = 0·108 of an inch in the day ‡. The mean of these two experiments is 0·084 inches, amounting for the whole

* Phil. Trans. vol. lxvii.—Dalton, Manchester Memoirs, v. 358.

† Tran. Philad. ii. 135.

‡ Watson's Chemical Essays, iii. 54.

month of June to 2·62 inches. If we suppose this to bear the same proportion to the whole year that the evaporation in Dr. Dobson's experiments for June do to the annual evaporation, we shall obtain an annual evaporation amounting to about 22 inches. This is much smaller than that obtained by Mr. Williams. But Dr. Watson's method was not susceptible of precision. He collected the vapour raised on the inside of a drinking-glass; but it was impossible that the glass could condense much more than one half of what did rise, or would have been raised, in other circumstances. But to counterbalance this, the experiments were made in the hottest part of the day, when much more vapour is raised than during any other part of it.

The most exact set of experiments on the evaporation from earth was made by Mr. Dalton and Mr. Hoyle during 1796 and the two succeeding years. The method which they adopted was this. Having got a cylindrical vessel of tinned iron, 10 inches in diameter, and three deep, there were inserted into it two pipes turned downwards for the water to run off into bottles: The one pipe was near the bottom of the vessel; the other was an inch from the top. The vessel was filled up for a few inches with gravel and sand, and all the rest with good fresh soil. It was then put into a hole in the ground, and the space around filled up with earth, except on one side, for the convenience of putting bottles to the two pipes; then some water was poured on to sodden the earth, and as much of it as would was suffered to run through without notice, by which the earth might be considered as saturated with water. For some weeks the soil was kept above the level of the upper pipe, but latterly it was constantly a little below it, which precluded any water running off through it. For the first year the soil at top was bare; but for the two last years it was covered with grass the same as any green field. Things being thus circumstanced, a regular register was kept of the quantity of rain-water that ran off from the surface of the earth through the upper pipe (whilst that took place), and also of the quantity of that which sunk down through the three feet of earth, and ran out through the lower pipe. A rain-gauge of the same diameter was kept close by to find the quantity of rain for any corresponding time. The weight of the water which ran through the pipes being subtracted from the water in the rain-gauge, the remainder was considered as the weight of the water evaporated

from the earth in the vessel. The following Table exhibits the mean annual result of these experiments *.

	Water through the two Pipes. Inch. 1796.	Inch. 1797.	Inch. 1798.	Mean Inch.	Mean Rain Inch.	Mean Evap. Inch.
January	1·897—	·680—	1·774+	1·450+	2·458	1·008
Feb.......	1·778—	·918—	1·122	1·273	1·801	·528
March...	·431—	·070—	·335	·279	·902	·623
April......	·220—	·295—	·180	·232	1·717	1·485
May......	2·027—	2·443+	·010	1·493+	4·177	2·684
June......	·171—	·726	——	·299	2·483	2·184
July......	·153—	·025	——	·050	4·154	4·095
August...	——	——	·504	·168	3·554	3·386
Sept.......	——	·976	——	·325	3·279	2·954
October	——	·680	——	·227	2·899	2·672
Nov.......	——	1·044	1·594	·879	2·934	2·055
Dec.......	·200	3·077	18·78+	1·718+	3·202	1·484
	6·877—	10·934—	7·379	84·02	33·560	25·158
Rain...	30·629—	38·791—	31·259			
Evap....	23·725—	27·857—	23·862			

From these experiments it appears, that the quantity of vapour raised annually at Manchester is about 25 inches: if to this we add five inches for the dew, with Mr. Dalton, it will make the annual evaporation 30 inches. Now if we consider the situation of England, and the greater quantity of vapour raised from water, it will not surely be considered as too great an allowance if we estimate the mean annual evaporation over the whole surface of the globe at 35 inches. Now 35 inches from every square inch on the superficies of the globe make 94,450 cubic miles, equal to the water annually evaporated over the whole globe.

Were this prodigious mass of water all to subsist in the atmosphere at once, it would increase its mass by about a twelfth, and raise the barometer nearly three inches. But this never happens; no day passes without rain in some part of the earth; so that part of the evaporated water is constantly precipitated again. Indeed it would be impossible for the whole of the evaporated water to subsist in the atmosphere at once, at least in the state of vapour.

* Manchester Memoirs, v. p. 360.

The higher regions of the atmosphere contain less vapour than the strata near the surface of the earth. This was observed both by Saussure and Deluc, who mentions several striking proofs of it.

At some height above the tops of mountains the atmosphere is probably still drier; for it was observed both by Saussure and Deluc, that on the tops of mountains the moisture of the air was rather less during the night than the day. And there can be little doubt that every stratum of air descends a little lower during the night than it was during the day, owing to the cooling and condensing of the stratum nearest the earth. Vapours, however, must ascend very high, for we see clouds forming far above the tops of the highest mountains.

[*Thomson's Chem.*

The exact cause of evaporation, however, is still doubtful. The chief theories are those of vesicular vapour; solution in air; electricity. Richman, in the St. Petersburgh Memoirs, thinks the evaporation nearly in proportion to the temperature. Franklin conceives that evaporation *properly* so called, is a solution of water in air, but that water or dust may be supported in the air by adhesion. Phil Trans. 1765. Desaguliers believes, that vapour may be raised by electric attraction in the air. He makes the specific gravity of steam $\frac{1}{14000}$, from observations by Beighton and himself; or $\frac{1}{13366}$ from Nieuwentyt's experiments on the eolipile; and hence infers, that vapour in summer heat should be about $\frac{1}{2058}$ as dense as water, and should therefore float in air. But from his own experiments the specific gravity should be about five times as great.—*Phil. Trans. Rep. of Arts.*

Eeles, Phil. Trans. 1775, contends against the existence of vesicular vapour, in favour of electrical atmospheres. Monge espoused the same side of the question: as did Eason, Manch. Mem. i. 395. Darwin, in remarking on Eeles's opinions, Phil. Trans. 1757, supposes that the particles of vapours are real steam, but incapable of communicating their heat, perhaps on account of some motion. Hamilton objects to both vesicles and to fixed fire, and maintains the doctrine of solution in air. Phil. Trans. 1765.

Deluc. Phil. Trans. 1792, maintains that vapour exists in air precisely as in a vacuum, the distance at which its particles can remain without uniting with each other being determined only by the tem-

perature, and not being affected by the interposition of air. Wernon, in Mem. Goth. vi. 1. opposes Deluc's theory: and both has ascertained, by many experiments, that the pressure of air is indifferent to the quantity of vapour.

Professor Parrot considers the moisture contained in air as existing in two distinct states, of chemical and of physical vapour: he thinks the chemical vapour is sustained merely by the oxygen gas contained in the air, and that it is precipitated in consequence of the diminution of the oxygen; and the physical vapour he supposes to be merely interposed between the interstices of the elastic particles of air, and retained in its situation by heat: that the chemical solution of water or ice resembles oxidation, but that no physical evaporation can take place under the freezing point. Mr. Parrot builds his theory principally on eudiometrical experiments with phosphorus, which are attended with a copious precipitation, while the absorption of oxygen seems also to be much accelerated by the presence of water; but these experiments do not appear to be, by any means, decisive in favour of Mr. Parrot's theory. The same paper contains a proposal for inoculating the clouds with thunder and lightning, by projecting a bomb to a sufficient height.

Halley calculated that the evaporation of the Mediterranean in a summer's day is 5280 million tuns, and that the nine principal rivers, furnish only 1827 millions. But the experiment on evaporation was made on a surface too small for the comparison.

The quantity of invisible moisture, contained in air, may be, in some degree, estimated from the indications of hygrometers, although these instruments have hitherto remained in a state of great imperfection. A sponge, a quantity of caustic potash, or of sulphuric acid, or a stone of a peculiar nature, has sometimes been employed for determining the degree of moisture of the air, from which it acquires a certain augmentation of its weight. A cord dipped in brine, or the beard of an oat, is also often used for the same purpose: the degree in which it untwists, from the effect of moisture, being shown by an index. But the extension of a hair, or of a slip of whalebone, which have been employed by Saussure and Deluc, appear to be more certain and accurate in their indications. The air hygrometer acquires more speedily the degree corresponding to any given state of the air, but it seems to

reach the utmost extent of its scale before it arrives at perfect humidity; while the whalebone hygrometer appears to express a greater change upon immersion in water than from the effect of the moistest transparent air, which has also been considered by some as an imperfection. Both these instruments are impaired by time, and acquire contrary errors, so that a mean between both is more likely to be correct than either separately. Their indications are at all times widely different from each other, and the mean appears to approach much nearer to a natural scale than either of them.

EDITOR.

CHAP. XXXIX.

FORMATION AND NATURE OF DEW, MIST, FOGS, CLOUDS, RAIN, SNOW, AND HAIL.

SECTION I.

General Remarks.

WHEN visible vapour has been deposited from transparent air, by means either of cold or some other cause, it generally remains for some time suspended, in the form of a mist or of a cloud: sometimes, however, it appears to be at once deposited on the surface of a solid, in the form of dew or of hoar frost; for it is not probable that the chrystallized form, in which hoar frost is arranged, can be derived from the union of the particles already existing in the air as distinct aggregates.

The dew, which is commonly deposited on vegetables, is partly derived, in the evening, from the vapours ascending from the heated earth, since it is then found on the internal surface of a bell glass; and towards the morning, from the moisture descending from the air above, as it begins to cool. Sometimes, however, in warmer weather, the dew begins to descend in the evening;

this the French call *serein:* the humidity deposited by mists on trees, and by moist air on windows, generally within, but sometimes without, they call *givre.*

It is well known that dew is often deposited on glass, when metals in its neighbourhood remain dry; Mr. Prévost has however discovered some new and curious facts relative to this deposition. When thin plates of metal are fixed on pieces of glass, it sometimes happens that they are as much covered with dew as the glass itself: but more frequently they remain dry; and in this case they are also surrounded by a dry zone. But when the other side of the glass is exposed to dew, the part which is opposite to the metal remains perfectly dry. If the metal be again covered with glass, it will lose its effect in preventing the deposition.

These experiments may be very conveniently made on the glass of a window, when moisture is attaching itself to either of its surfaces; Mr. Prévost remarks that it often happens that dew is deposited externally, even when the air within is warmer than without. A plate of metal fixed internally on the window receives a larger quantity of moisture than the glass, while the space opposite to an external plate remains dry: and if the humidity is deposited from without, the place opposite the internal plate is also more moistened, while the external plate remains dry: and both these circumstances may happen at once with the same result. A small plate fixed externally, opposite to the middle of the internal plate, protects this part of the plate from receiving moisture, and a smaller piece of glass, fixed on the external plate, produces again a central spot of moisture on the internal one: and the same changes may be continued for a number of alternations, until the whole thickness becomes more than half an inch. Gilt paper, with its metallic surface exposed, acts as a metal, but when the paper only is exposed, it has no effect. When a plate of metal, on which moisture would have been deposited, is fixed at a small distance from the glass, the moisture is transferred to the surface of the glass immediately under it, without affecting the metal: if this plate is varnished on the surface remote from the glass, the effect remains, but if on the side next the glass, it is destroyed. The oxidation of metals renders them also unfit for the experiment. When glasses partly filled with mercury, or even with water, are exposed to the dew, it is deposited only on the parts

which are above the surface of the fluid. But in all cases when the humidity is too copious, the results are confused.

In order to reduce these facts to some general laws, Mr. Prévost observes, that when the metal is placed on the warmer side of the glass, the humidity is deposited more copiously either on itself or on either surface of the glass in its neighbourhood: but that, when it is on the colder side, it neither receives humidity, nor permits its deposition on the glass: that a coat of glass, or varnish, destroys the efficacy of the metal, but that an additional plate of metal restores it.

Mr. Prévost was at first disposed to attribute these phænomena to the effects of electricity, but he thinks it possible to explain them all by the action of heat only: for this purpose he assumes, first, that glass attracts humidity the more powerfully as its temperature is lower; secondly, that metals attract it but very little; thirdly, that glass exerts this attraction notwithstanding the interposition of other bodies; and fourthly, that metals give to glass, placed in their neighbourhood, the power of being heated by warm air, and being cooled by cold air, with greater rapidity: hence that the temperature of the glass approaches more nearly to that of the air on the side opposite to the metal, and attracts the humidity accordingly more or less, either to its own surface, or to that of the metal. We should indeed have expected a contrary effect; that the metal would rather have tended to communicate to the glass the temperature of the air on its own side: but granting that the assumptions of Mr. Prévost serve to generalise the facts with accuracy, their temporary utility is as great as if they were fundamentally probable.

Hence dew is perhaps nothing more than a portion of the vapour formerly suspended in the atmosphere, condensed by means of the cold of the evening. It has been observed with surprise that when a number of bodies are exposed together to the dew, some are quite wetted with it, while others remain dry. This circumstance probably depends upon the goodness of the body as a conductor of heat. Good conductors will part with their heat more readily, and will therefore evaporate the dew again, whereas it will remain upon bad conductors, which will not so easily part with their heat. If this explanation be the true one, it follows that bodies exposed to the dew and dry, must have a lower temperature than those

which remain moist. The following Table, by Dr. Stocke, exhibits the relative quantity of dew remaining upon a variety of bodies *.

Bodies.	Effect.	Bodies.	Effect.
Glass	Much dew.	Polished lead	A little.
Polished brass	Very little.	Silver	None.
Rough brass	A little more.	Silver gilded	None.
Lattin or iron tinned	A little.	Blue porcelain	None.
Ditto rough	Very much.	A stone slab	Much.
Ditto smooth	Scarce any.	Basket of Indian cane	A little.
Ditto rusty	None.	Smooth white oaken plank	Very much.
Quicksilver	None.	Ditto black	Much less.
Smooth tin	None.	Smooth fir plank	Little.
Rough lead	Much.		

If these experiments be accurate, it is obvious that the goodness of the bodies as conductors of heat will not account for the phænomenon. Perhaps we must look for it in the goodness of the bodies as conductors of electricity.

Mists are said to consist sometimes of other particles than pure water: these are called dry mists, and they have been supposed to blight vegetables. Such mists are sometimes attended by a smell, resembling that which is occasioned by an electric spark. Rain falling after a dry season deposits, when it has been suffered to stand, some particles of foreign matter which it has brought down from the atmosphere. There must indeed frequently be a multiplicity of substances of various kinds floating in the air; the wind has been found to carry the farina of plants as far as 30 or 40 miles, and the ashes of a volcano more than 200. It only requires that the magnitude of the particles of any substances be sufficiently reduced in size, in order to render them incapable of falling with any given velocity; and when this velocity is very small, it may easily be overpowered by any accidental motions of the air. The diameter of a sphere of water, falling at the rate of one inch only in a second, ought to be one six hundred thousandth of an inch, which is about the thickness of the upper part of a soap bubble at the instant when it bursts; but the particles of mist are incomparably larger than this, since they would otherwise be perfectly invisible

* Phil. Trans. 1742, vol. xli, p. 112.

as separate drops: the least particle, that could be discovered by the naked eye, being such as would fall with a velocity of about a foot in a second, if the air were perfectly at rest. But it is very probable that the resistance, opposed to the motion of particles so small, may be considerably greater, than would be expected from a calculation, derived from experiments made on a much larger scale, and their descent consequently much slower.

When the particles of a mist are united into drops capable of descending with a considerable velocity, they constitute rain; if they are frozen during their deposition, they exhibit the appearance of a perfect crystallization, and become snow: but if the drops already formed are frozen, either by means of external cold, or on account of the great evaporation produced by a rapid descent through very dry air, they acquire the character of hail, which is often observed in weather much too hot for the formation of snow.

It cannot be doubted but that there is a connection between the descent of the barometer and the fall of rain; but no satisfactory reason has yet been assigned for the circumstance; nor is it possible to foretel, with certainty, that rain will follow any changes in the height of the barometer that have been observed. The immediate dependence of rain, or of any other atmospherical phænomena, on the influence of the moon, appears to be rendered highly improbable, not only by mathematical calculations of the effects of the moon's attraction, but also by the irregularity of the very observations, which have been adduced in favour of such a connexion.

But however uncertain the ultimate causes of rain may be in general, their effects in some places are sufficiently constant to be attributed to permanent local circumstances, and in particular to the periodical recurrence of similar winds.

In low and level countries, clouds may often begin to descend from the upper regions of the atmosphere, and may be redissolved by the warmer air below; but when they descend in an equal degree among mountains, they fall on the earth; and besides the quantity of water which they furnish for vegetation, and that which is carried off by evaporation, they afford by means of springs and rivers, a constant supply for the use of man and of other animals in distant parts. The upper regions of the atmosphere are however by no means the principal sources of rain in ordinary climates, since a gauge placed on a very high building seldom collects more

than two-thirds as much rain as another standing on the ground below: and the effects of mountains in collecting rain are perhaps chiefly derived from the ascending currents which they occasion, and by which the air saturated with moisture is carried to a higher and a colder region.

The Abyssinian rains are the causes of the inundation of the Nile; they last from April to September; but for the first three months the rain is only in the night. The inundation, in Egypt, begins at present about the 17th of June; it increases for forty days, and subsides in the same time; but the ancient accounts, as well as some modern ones, assign a longer duration to it. The river Laplata rises and falls at the same times as the Nile. The Ganges, the Indus, the Euphrates, the river of Ava or Pegu, and many other large rivers, have also considerable inundations at regular periods. In many other countries there are seasons at which the rains seldom fail to recur; and sometimes the periodical rains are different in different parts of the same country. Thus the coast of Malabar, which is to the west of the Gate mountains, or Gauts, enjoys summer weather, without rain from September to April, while that of Coromandel, which is on the eastern side, experiences all the rigours of its winter; being at this time exposed to the influence of the north-east trade wind. Vicissitudes of a similar nature are also observed on the north and south sides of the island of Jamaica.

[*Young. Thomson. Phil. Trans.*

It has been a matter of great contest among philosophers by which means water, which is nearly nine hundred times heavier than air, can be rendered capable of ascending into the aërial regions. Descartes accounted for it by supposing that by the action of solar heat upon a sheet of water, its superficial particles are formed into little hollow spheres, and become filled with the *materia subtilis* of space, on a minute substance not unlike the primal atoms of Lucretius, and which Des Cartes conceived to be frequently employed in the formation of clouds. The particles of water thus filled, must necessarily, it was added, from the superior levity of the substance they envelop, ascend through the ambient air till they attain the proper level.

The theory of Dr. Halley was not very different, varying alone

in the supposition that the detached and ascending vesicles of water are impregnated with highly rarefied air, instead of with the subtile ether of Des Cartes.

But the hypothesis now generally admitted is that of solution, first of all advanced by the Abbé Nollet, in his *Leçons de Physique Experimentale.* Water and air, it is contended, have a mutual power of dissolving each other; and air is not more frequently extricated from the former than water is from the latter. The lower part of the atmosphere being pressed, then, by the weight of the incumbent column on the surface of the water, and perpetually rubbing against it, attracts and dissolves those particles with which it is in contact, and separates them from the rest of the water. The aqueous particles thus detached, and absorbed by the lower column of air, are, next, still more forcibly attracted by the superior, in consequence both of its being drier, and possessing ampler pores to receive the dissolved vapour. When the aqueous particles attain a certain degree of elevation, the coldness of the atmosphere condenses them, and they coalesce into particles of a larger diameter, and gradually produce the phenomenon of a CLOUD. When the particles, of which such cloud consists, are more closely compacted, either by the mutual attraction of cohesion, or the external pressure of the wind against it, they run into drops sufficiently ponderous to descend in the form of RAIN. If the cloud become frozen by any current of cold air, before its particles are formed into drops, small fragments of them being condensed, and consequently increased in weight, will detach themselves from the general mass, and fall down in thin flakes of SNOW. If its particles have coalesced into drops prior to its being frozen, these drops will then descend in the form of HAIL-*stones.* And when the lower air is replete with aqueous vapour dissolved in its pores, and a sudden current of cold wind brushes through it, producing the natural frigidity of the superior atmosphere, a MIST or FOG, which is only a kind of inferior cloud, is immediately created; and as suddenly again dispersed on the return of the natural warmth of the air, which then redissolves, to invisible minuteness, the vapoury particles. In like manner DEW-*drops* may be regarded as a species of inferior rain, the cold attaching the dissolved vapours of the lower atmosphere, being either more intense than in the case of fogs, or continued for a greater length of time.

[GOOD's *Trans. of Lucretius, Note on Book* vi. 467.

Rain never begins to fall while the air is transparent: the invisible vapours first pass their maximum, and are changed into vesicular vapours; clouds are formed, and these clouds gradually dissolved in rain. Clouds, however, are not formed in all parts of the horizon at once; the formation begins in one particular spot, while the rest of the air remains clear as before: this cloud rapidly increases till it overspreads the whole horizon, and then the rain begins.

It is remarkable, that though the greatest quantity of vapours exist in the lower strata of the atmosphere, clouds never begin to form there, but always at some considerable height. It is remarkable too, that the part of the atmosphere at which they form, has not arrived at the point of extreme moisture, nor near that point, even a moment before their formation. They are not formed, then, because a greater quantity of vapour had got into the atmosphere than could remain there without passing its maximum. It is still more remarkable, that when clouds are formed, the temperature of the spot in which they are formed is not always lowered, though this may sometimes be the case. On the contrary, the heat of the clouds themselves is sometimes greater than that of the surrounding air *. Neither, then, is the formation of clouds owing to the capacity of air for combining with moisture being lessened by cold; so far from that, we often see clouds, which had remained in the atmosphere during the heat of the day, disappear in the night, after the heat of the air was diminished.

The formation of clouds and rain, then, cannot be accounted for by the principles with which we are acquainted. It is neither owing to the saturation of the atmosphere, nor the diminution of heat, nor the mixture of airs, of different temperatures, as Dr. Hutton supposed; for clouds are often formed without any wind at all either above or below them; and even if this mixture constantly took place, the precipitation, instead of accounting for rain, would be almost imperceptible.

It is a very remarkable fact, that evaporation often goes on for a month together in hot weather without any rain. This sometimes happens in this country; it happens every year in the torrid zone. Thus at Calcutta, during January 1785, it never rained at all †: the mean of the thermometer for the whole month was $66\frac{1}{2}$ degrees;

* De Luc sur la Meteorol. ii. 100. † Asiatic Researches, vol. ii. Appendix.

there was no high wind, and indeed during great part of the month little wind at all.

The quantity of water evaporated during such a drought must be very great; yet the moisture of the air, instead of being increased, is constantly diminishing, and at last disappears almost entirely; for the dew, which is at first copious, diminishes every night: and if Dr. Watson's experiment formerly mentioned be attended to*, it will not be objected that the quantity of evaporation is also very much diminished. Of the very dry state to which the atmosphere is reduced during long droughts, the violent thunderstorms with which they often conclude is a proof, and a very decisive one. Now what becomes of all this moisture? It is not accumulated in the atmosphere above the conntry from which it was evaporated, otherwise the whole atmosphere would in a much less period than a month be perfectly saturated with moisture. If it be carried up daily through the different strata of the atmosphere, and wafted to other regions by superior currents of air, how is it possible to account for the different electrical state of the clouds situated between different strata, which often produces the most violent thunder storms? Are not vapours conductors of the electric fluid? and would they not have daily restored the equilibrium of the whole atmosphere through which they passed? Had they traversed the atmosphere in this manner, there would have been no negative and possitive clouds, and consequently no thunder-storms. They could not have remained in the lower strata of the atmosphere, and been daily carried off by winds to other countries; for there are often no winds at all during several days to perform this office; nor in that case would the dews diminish, nor could their presence fail to be indicated by the hygrometer.

It is impossible for us to account for this remarkable fact upon any principle with which we are acquainted. The water can neither remain in the atmosphere, nor pass through it in a state of vapour. It must therefore assume some other form; but what form, or how it assumes it, we know not.

There are, then, two steps of the process between evaporation and rain, of which at present we are completely ignorant: 1. What

* See p. 134.

becomes of the vapour after it enters into the atmosphere. 2. What makes it lay aside the new form which it must have assumed, and return again to its state of vapour, and fall down in rain. And till these two steps be discovered by experiments and observations, it will be impossible for us to give a rational or a useful theory of rain.

Dr. Pratt of Exeter has endeavoured to prove, in a very ingenious treatise, that water is decomposed during its evaporation, and converted into oxygen and hydrogen gas; but the absence of any perceptible quantity of this last gas in the atmosphere, even when rain is actually forming, cannot be accounted for, unless we suppose that the products of the decomposition are different. Girtanner's theory, that azote is composed of hydrogen and oxygen, would remove every difficulty; but unfortunately that theory is not only destitute of proof, but militates against the known properties of water, azote, and hydrogen. We must therefore be cautious in drawing any conclusion till future discoveries have removed the obscurity in which the phænomena of rain are at present involved.

The mean annual quantity of rain is greatest at the equator, and decreases gradually as we approach the poles. Thus at

* Granada, Antilles,	12° N. lat. it is		126 inches
* Cape François, St. Domingo	19°	46′	120
† Calcutta	22	23	81
‡ Rome	41	54	39
§ England	33	00	32
‖ Petersburg	59	16	16

On the contrary, the number of rainy days is smallest at the equator, and increases in proportion to the distance from it. From north latitude 12° to 43° the mean number of rainy days is 78; from 43° to 46° the mean number is 103; from 46° to 50° it is 134; from 51° to 60°, 161 ¶.

* Cotte, Jour. de Phys. Oct. 1791, p. 246.
† Asiatic Researches, i. and ii. Appendix.
‡ Cotte, Jour. de Phys. Oct. 1791. p. 264.
§ Phil. Trans.
‖ Edin. Trans. ii. 244.
¶ Cotte, Jour. de Phys. Oct. 1791, p. 264.

The number of rainy days is often greater in winter than in summer; but the quantity of rain is greater in summer than in winter*. At Petersburgh the number of rainy or snowy days during winter is 84, and the quantity which falls is only about five inches; during summer the number of rainy days is nearly the same, but the quantity which falls is about 11 inches†.

More rain falls in mountainous countries than in plains. Among the Andes it is said to rain almost perpetually, while in Egypt it hardly ever rains at all. If a rain-gauge be placed on the ground, and another at some height perpendicularly above it, more rain will be collected into the lower than into the higher; a proof that the quantity of rain increases as it descends, owing perhaps to the drops attracting vapour during their passage through the lower strata of the atmosphere, where the greatest quantity resides. This, however, is not always the case, as Mr. Copland, of Dumfries, discovered in the course of his experiments ‡. He observed, also, that when the quantity of rain collected in the lower gauge was greatest, the rain commonly continued for some time; and that the greatest quantity was collected in the higher gauge only either at the end of great rains, or during rains which did not last long. These observations are important, and may, if followed out, give us new knowledge of the causes of rain. They seem to show, that during rain the atmosphere is somehow or other brought into a state which induces it to part with its moisture; and that the rain continues as long as this state continues. Were a sufficient number of observations made on this subject in different places, and were the atmosphere carefully analysed during dry weather, during rain, and immediately after rain, we might soon perhaps discover the true theory of rain.

Rain falls in all seasons of the year, at all times of the day, and during the night as well as the day; though, according to M. Toaldo, a greater quantity falls during the day than the night. The cause of rain, then, whatever it may be, must be something which operates at all times and seasons. Rain falls also during the continuance of every wind, but oftenest when the wind blows from the south. Falls of rain often happen likewise during perfect calms.

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* Id. ibid.

† Edin. Trans. ii. 244.

‡ Manchester Trans. iv. 619.

It appears from a paper published by M. Cotte in the Journal de Physique for October 1791, containing the mean quantity of rain falling at 147 places, situated between north lat. 11° and 60°, deduced from tables kept at these places, that the mean annual quantity of rain falling in all these places is 34·7 inches. Let us suppose then (which cannot be very far from truth) that the mean annual quantity of rain for the whole globe is 34 inches. The superficies of the globe consists of 170,981,012 square miles, or 686,401,498,471,475,200 square inches. The quantity of rain therefore falling annually will amount to 23,337,650,812,030,156,800 cubic inches, or somewhat more than 91,751 cubic miles of water.

The dry land amounts to 52,745,253 square miles; the quantity of rain falling on it annually therefore will amount to 30,960 cubic miles. The quantity of water running annually into the sea is 13,140 cubic miles; a quantity of water equal to which must be supplied by evaporation from the sea, otherwise the land would soon be completely drained of its moisture.

SECTION II.

Annual Fall of Rain, from Erxleben, Dalton, and others, with subjoined Remarks.

Upsal .... Inches	16·7	Lyndon, Rutl. 21 y.	24·3
West Bridgford, Notting.	17·0	Utrecht	24·7
Wittenberg	17·0	Haarlem	24·7
St. Petersburg	17·2	Youngsbury, Hartf. 5 y.	25·0
Lund	18·5	Kimbolton, Hunt.	25·0
Diss, Norfolk	18·7	Norwich, 13 y.	25·5
Upminster, Essex	19·5	Fyfield, Hampsh. 7 y.	25·9
Carlisle, 1 y.	20·2	Ferryby, Yorksh.	26·9
Paris	20·2	Chichester	26·8
Berlin	20·6	Ulm	27·0
Widdrington, North. 1 y.	21·2	Algiers	27·0
Rome	21·3	Barrowby, Yorksh. 6 y.	27·5
Edinburgh	22·0	Chatsworth, Derbysh. 15 y.	27·8
Dublin	22·2	Hague	28·4
South Lambeth, 9 y.	22·7	Delft	28·6
London, 7 y.	23·0	Harderwyk	28·6
Near Oundle, North. 14 y.	23·0	A place in Cornwall, 1 y.	29·1
Lisle	24·0	Bristol, 3 y.	29·2

Bridgwater, Somers.	29·3	Venice	36·1
Abo	29·3	Selbourne, Hampsh.	37·2
Leyden	30·2	Dover, 5 y.	37·5
Madeira	31·0	Lyons	39·4
Minehead, Somers	31·3	Kirkmichael, Dumfr.	40·8
Dalton's Mean for all England, taking first a mean of the counties	31·8	Ludgvan, Cornw.	41·0
		Dordrecht	41·0
		Townley, Lanc. 15 y.	41·5
Mean of 16 places in Great Britain, Enc. Br.	32·6	Pisa	43·2
		Lancaster, 10 y.	45·0
Dalton's immediate mean of 32 places, mostly rainy	35·2	Waith. Sutton, Westm. 5 y.	46·0
		Plymouth, 2 y.	46·5
Manchester, 9 y.	33·0	Charlestown	50·9
Middleburgh	33·0	Garsdale, Westm. 3 y.	52·3
Zurich	33·1	Fellfoot, Westm. 3 y.	55·7
Exeter	33·2	Kendal, Westm. 11 y.	59·8
Liverpool, 18 y.	34·4	Kendal, in 1782	83·5
Padua	34·5	Crawshawbooth, Lanc. 2 y.	60·0
Cotte's mean of 147 places	34·7	Keswick, Cumb. 7 y.	67·0
Sienna	35·2	East Indies, sometimes	104·0

[*Young's Nat. Phil.*

For rain and dew together Dalton makes the mean of England and Wales 36 inches, amounting in a year to 28 cubic miles of water.

From observations made in 1804 at Exeter, Chichester, London, Diss, Chatsworth, W. Bridgford, Ferriby, Lancaster, and Kendal, it appears that December was the wettest month in four of these places; June in two, May and November each in one, and April and December in one instance equally wetter than the rest.

Erxleben asserts, ii. 735, that the drops of rain at the equator are sometimes an inch in diameter.

Ulloa affirms that it never rains in Peru; but that for a part of the year the atmosphere is obscured by thick fogs, called garuas.

In some parts of Arabia it seldom rains more than two or three times in two or three years; but the dews are heavy, and refresh the soil and supply the few plants, which grow in these regions, with moisture.

[*Editor.*

SECTION III.

Fall of Butter-like Dew in different Parts of Ireland.

This curious phænomenon is noticed in two separate articles in vol. xix. of the Philosophical Transactions. The first is an extract of a letter from Mr. Robert Vans of Kilkenny, dated Nov. 15, 1695, as follows:

"We have had of late, in the county of Limerick and Tipperary, showers of a matter, like butter or grease. If this be rubbed on one's hand, it will melt, but laid by the fire, it dries and grows hard, having a very stinking smell. This last night some fell at this place, which I saw this morning. It is gathered into pots and other vessels, by some of the inhabitants of this place.

The second article is still more minute, and proceeds from the well-known pen of the Bishop of Cloyne, bearing date April 1696.

"Having very diligently inquired concerning a very odd phenomenon, which was observed in many parts of Munster and Leinster, the best account I can collect of it is as follows: For a good part of last winter and spring, there fell in several places, a kind of thick dew, which the country people called butter, from the consistency and colour of it, being soft, clammy, and of a dark yellow; it fell always in the night, and chiefly in moorish low grounds, on the top of the grass, and often on the thatch of cabins. It was seldom observed in the same places twice: it commonly lay on the earth for near a fortnight, without changing its colour; but then dried and turned black. Cattle fed in the fields where it lay indifferently, as in other fields. It fell in lumps, often as large as the end of one's finger, very thin and scatteringly; it had a strong ill scent, somewhat like the smell of church-yards or graves; and indeed we had during most of that season very stinking fogs, some sediment of which might probably occasion this stinking dew, though I will by no means pretend to offer that as a reason of it: I cannot find that it was kept long, or that it bred any worms or insects; yet the superstitious country people, who had scald or sore heads, rubbed them with this substance, and said it healed them."

[*Phil. Tran.* 1696.

We have already had occasion to observe that substances of various kinds are frequently carried into the atmosphere by their own levity or other force. Fat or butter is nothing more than a mixture of hydrogen and carbon in certain relative proportions to each other. Both these substances are often extricated from the surface of the low moorish grounds here referred to; and from their affinity to each other, very generally ascend in combination, forming what the chemists call hydro-carbonat, or curburetted hydrogen gas: and hence, in the instance before us, the combination of these two substances was in all probability such as to produce the unctuous material here described *. [EDITOR.

SECTION IV.

Dense Fog on the Island of Sumatra.

By William Marsden, Esq.

In the year 1775 the S. E. or dry monsoon, set in about the middle of June, and continued with very little intermission till the month of March in the following year. So long and severe a drought had not been experienced there in the memory of the oldest man. The verdure of the ground was burnt up, the trees were stripped of their leaves, the springs of water failed, and the earth every where gaped in fissures. For some time a copious dew falling in the night supplied the deficiency of rain; but this did not last long: yet a thick fog, which rendered the neighbouring hills invisible for months together, and nearly obscured the sun, never ceased to hang over the land, and added a gloom to the prospect already but too melancholy. The Europeans on the coast suffered extremely in sickness; about a fourth part of the whole number being carried off by fevers and other bilious distempers, the depression of spirits which they laboured under, not a little contributing to hasten the fatal effects. The natives also died in great numbers.

* The substance called *Honey-dew* does not regularly belong to this division of our work. It is usually an excrementitious secretion of various insects that adhere to the lower surface of the leaves of plants; and we shall notice it accordingly in the subsequent divisions of the Gallery of Nature and Art which will be found to comprise the curiosities of Zoology. The dew of plants is in like manner an aqueous secretion from the secernent vessels of plants. EDITOR.

In the month of November that year, the dry season having then exceeded its usual period, and the S. S. winds continuing with unremitting violence, the sea was observed to be covered, to the distance of a mile, and in some places a league from shore, with fish floating on the surface. Great quantities of them were at the same time driven on the beach or left there by the tide, some quite alive, others dying, but the greatest part quite dead. The fish thus found were not of one but various species, both large and small, flat and round, the cat-fish and mullet being generally the most prevalent. The numbers were prodigious, and overspread the shore to the extent of some degrees; of this I had ocular proof or certain information, and probably they extended a considerable way farther than I had opportunity of making enquiry. Their first appearance was sudden; but though the numbers diminished, they continued to be thrown up, in some parts of the coast, for at least a month, furnishing the inhabitants with food, which, though attended with no immediate ill consequence, probably contributed to the unhealthiness so severely felt. No alteration in the weather had been remarked for many days previous to their appearance. The thermometer stood as usual at the time of year at about 85°.

Various were the conjectures formed as to the cause of this extraordinary phenomenon, and almost as various and contradictory were the consequences deduced by the natives from an omen so portentous; some inferring the continuance, and others with equal plausibility, a relief from the drought. With respect to the cause I must confess myself much at a loss to account for it satisfactorily. If I might hazard a conjecture, and it is not offered as any thing more, I would suppose, that the sea requires the mixture of a due proportion of fresh water to temper its saline quaility, and enable certain species of fish to subsist in it. Of this salubrious correction it was deprived for an unusual space of time, not only by the want of rain, but by the ceasing of many rivers to flow into it, whose sources were dried up. I rode across the mouths of several perfectly dry, which I had often before passed in boats. The fish no longer experiencing this refreshment, necessary as it would seem to their existence, sickened and perished as in a corrupted element.

[*Phil. Trans.* 1781.

SECTION V.

Violent showers of Rain at Denbigh: in a communication to Dr. (Sir Hans.) Sloane, Secretary to the Royal Society.

Tuesday the 16th of July, 1706, about eight o'clock in the morning, it began to rain in and about Denbigh, which continued incessantly for thirty hours, but not very violently till about three or four o'clock on Wednesday morning, when it rained somewhat faster, attended with a terrible noise like thunder, with some flashes of lightning, and a boisterous wind. About break of day the rain and wind began to abate of their violence, lessening gradually till about one or two o'clock in the afternoon, when it quite ceased, and the air became clear and somewhat calm. On the Tuesday the wind blew south west, but on the Wednesday it was come to the north west.

The effects of this great storm were dismal, for it caused the overflowing of all the rivers in Denbighshire, Flintshire, and Merionethshire, &c. which spoiled a great deal of corn, and took off all the hay that was mowed, near the banks of the rivers, which were carried by the stream in such vast quantities down to the bridges that it choked the arches and inlets, so as to break down above a dozen large bridges. Great oaks and other large trees were rooted up and swept away, with several quickset hedges, and some quillets by the side of the river Elwy were so covered with stones and gravel, that the owners cannot well tell whereabouts their hedges and landmarks stood; and the same river has altered its course in some places, so as to rob the landlords on one side of some acres, aud bestowed as much on the opposite side. Two or three rivulets that conveyed water to some mills have been so choked up with stones and gravel, as to make it hardly worth the expence of clearing.

It is affirmed by many people that the great floods were not so much the effects of the rain, as the breaking out of a vast number of springs, in such places as they were never known to flow from before. In the town of Denbigh a great many broke out in the houses and stables, especially in that part which lies next the castle on the north side; some of them with a great deal of violence, and in such a quantity, that it is said that three of these

new springs, which flowed out of the stables of the three noted inns, viz. the Bull, Cross Keys, and Boar's Head, were sufficient to turn any corn mill.

At a small distance, northward of Denbigh, lies Park Snodiog, a rocky hill, out of which issued a great many springs, which flowed so plentifully for nine or ten days, that the cattle watered at them all that time; whereas, before and after, the people were forced to water them all summer at a well in the highway, at some distance from Park Snodiog. There are several deep holes and trenches cut in the highways adjoining to the river Elwy, &c. and some of them very large, which is attributed not so much to the overflowing of the river as to the breaking out of springs in those very places.

In Comb mountain there is a pit of a circular form, which in the summer time used to have little or no water in it, and in winter as much water as would swell the surface to about 14 or 16 yards over: but now in the midst of summer it rose up at least a yard and a half higher, than it was ever known to do in the wettest winters; and overflowing its banks, it fell down the hill with such violence, as to penetrate into the very body of a rock road, and dug pits in it, so that the road, which was a common highway, is now become irreparable.

[*Phil. Trans.* 1783.

2. *At Ripponden.*

By Mr. Ralph Thoresby, F.R.S.

The effects of a violent shower of rain at Ripponden, near Halifax, were so surprising, that I wrote to a gentleman in those parts for an account that might be depended on; and particularly desired to know, whether there was not an eruption of waters out of the hills, as the late Mr. Townley wrote me there was out of Pendle-hill, in that at Star-bottom mentioned in the Philos. Trans. No. 245: but all the account I can learn of this is, that what they call the dashing of two great watery clouds on the hills, occasioned the inundation; whatever was the more immediate cause, the effects were dismal, and so sudden, that though it was in the day-time, the poor people could not save their lives. This calamity happened May 18, 1722, between the hours of three and five, when the beck was raised more than two yards in perpendi-

cular height, above what was ever known before. Several houses, four mills, some say six, nine stone-bridges, and ten or eleven of wood, are broken down, and the wheels, dams, and sluices, of most of the mills that are left standing, broken and damaged; and a great deal of cloth gone. Fifteen persons were drowned.

The rapidity of the torrent was so violent, that it broke down the north-side of Ripponden chapel, and carried off most of the seats. It tore up the dead out of their graves. It swept away all the corn-land, as deep as the plough had gone. Some persons saved themselves by forcing a way out of the roofs of their houses, and sitting upon the ridges till the flood abated.

[*Phil. Trans.* 1772.

SECTION VI.

Storm of Salt Rain.

Along with the water, gaseous and other light materials that frequently ascend into the atmosphere in the usual process of evaporation, we occasionally meet with a combination of much heavier, and more unexpected substances, when the force of wind, volcanic eruptions, local electricity, or some other concurrent power is present and in great activity. The following is a singular instance of the kind, and made so striking an impression at the time, that the Philosophical Transactions contain three separate articles upon it; which, as each contains circumstances unnoticed by the rest, we shall give in their regular order. The three ensuing sections, however, will be found to offer still more extraordinary examples.

[Editor.

1. *Salt-storm in Sussex: as described in a Letter from John Fuller, Esq. Dec.* 6, 1703.

We live ten miles from the sea in a direct, and yet cannot persuade the country people but that the sea water was blown thus far, or that during the tempest the rain was salt; for all the twigs of the trees the day after were white and tasted very salt, as I am informed almost by every body, though I did not taste them time enough myself, nor observe it; and that not only upon this hill where we live facing the sea, but in all other places within fourteen

or fifteen miles of the sea, as well in the valleys, between which and the sea are several very high hills, as on the hills themselves.

2. *Observations on the above, by the Rev. William Derham, F.R.S.*

Of the preceding parts of this year, the months of April, May, June, and July, were wet in the southern parts of England; particularly in May, when more rain fell than in any month of any year since 1696; June also was very wet; and though July had considerable intermissions, yet on the 28th and 29th there fell violent showers of rain. And the newspapers gave accounts of great rains that month from divers places of Europe; but the north of England (which also escaped the violence of the late storm) was not so remarkably wet in any of those months; at least not in that great proportion, more than in the southern parts, as usually there are; particularly July was a dry month with them. September with us was a wet month, especially the latter part of it. October and November, though not remarkably wet, yet have been open warm months for the most part. My thermometer, the freezing point of which is about 84, has been very seldom below 100 all this winter, and especially in November.

Thus I have given a short account of the preceding disposition of the year, particularly as to wet and warmth; because I am of opinion that these had a great influence on the late storm; not only in causing a repletion of vapours in the atmosphere, but also in raising such nitro-sulphureous or other heterogeneous matter, which when mixed together might make a sort of explosion, like fired gunpowder, in the atmosphere: from which explosion I judge those corruscations or flashes in the storm proceeded, which most people, as well as myself observed, and which some took for lightning.

On Thursday, Nov. 25, the day before the tempest, in the morning there was a little rain, the winds high in the afternoon, at S. by E. and S. In the evening there was lightning, and between nine and ten o'clock at night, a violent but short storm of wind and much rain, at Upminster, and of hail in some other places, which did some damage. Next morning, November 26,

the wind was S. S. W. and high all day, and so continued till I was in bed and asleep. About twelve that night the storm awakened me, which gradually increased till near three that morning. And from thence, till near seven, it continued with the greatest violence; then it began to abate slowly, and the mercury to rise swiftly. The barometer I found, at $12\frac{1}{2}$ hours P. M. at 28·72, where it continued till about six the next morning, and then hastily rose; so that it was gotten to 82 about eight o'clock.

The degrees of the wind's strength not being measurable, but by guess, I thus determined with respect to other storms: on February 7, 1699, was a terrible storm, that did much damage: this I number 10 degrees; the wind then W. N. W. *vide* Phil. Trans. N° 262. Another remarkable storm was Feb. 3, 1702, at which time was the greatest descent of the mercury ever known: this I number 9 degrees. But this last of November, I number at least 15 degrees.

I have accounts of the violence of the storm at Norwich, Beccles, Sudbury, Colchester, Rochford, and several other intermediate places.

I have just received an account from a clergyman, an intelligent person, at Lewes, in Sussex, not only that the storm made great desolations thereabouts, but also an odd circumstance was occasioned by it; *viz.* "That a physician, travelling soon after the storm to Tisehyrst, about 20 miles from Lewes, and as far from the sea, as he rode he plucked some tops of hedges, and chewing them he found them salt. Some ladies of Lewes hearing this, tasted some grapes that were still on the vines, and they also had the same relish. The grass on the downs in his parish was so salt, that the sheep in the morning would not feed, till hunger compelled them, and afterwards drank copiously, as the shepherds report. This he attributes to saline particles driven from the sea. He hears also, that people about Portsmouth were much annoyed with sulphureous fumes, complaining they were almost suffocated with them."

3. *Additional Observations on the Same,*

By M. Leuwenhoeck.

Upon the 8th of December, 1703, N. S. we had a dreadful storm from the south-west, insomuch that the water, mingled with small

parts of chalk and stone, was so dashed against the windows, that many of them were darkened with it; and the lower windows of my house were not opened till eight o'clock that morning, notwithstanding that they look to the north-east, and consequently stood from the wind, and though guarded from the rain by a kind of shelf or pent-house over them, were yet so covered with the particles of the water which the whirlwind cast against them, that in less than half an hour they were deprived of most of their transparency. Supposing this might be sea-water which the storm had not only dashed against our windows, but spread also over the whole country, I viewed the particles with my microscope, and found they had the figure of our common salt, but very small, because the water was little from whence those small particles proceeded; and where the water had lain very thin upon the glass, there were indeed a great number of salt particles, but so exceedingly fine, that they almost escaped the sight through a very good microscope.

But as to the upper windows, where the rain had beat against them, and washed them, there was little or no salt to be found sticking upon them.

During the said storm, and about eight o'clock in the morning, casting my eye on my barometer, I observed that I had never seen the quicksilver so low; but, half an hour after, the quicksilver began to rise, though the storm was not at all abated, at least to any appearance; from whence I concluded that the storm would not last long; and so it happened accordingly. Some persons fear that the scattering of this salt-water by the storm will do a great deal of harm to the fruits of the earth; but, for my part, I am of a quite different opinion; for, I believe, that a little salt spread over the surface of the earth, especially where it is heavy clay-ground, renders it very fruitful; and so it would be if the sea-sand were made use of to the same purpose.

[*Phil. Trans.* 1704.

SECTION VII.

Volcanic Showers or Rain.

1. *General Remarks.*

The enormous violence with which, during eruptions, the materials that compose the bowels of the volcano are ejected into the atmosphere, and the disturbance which is usually communicated to the aerial regions, produce a conjoint force, which is frequently sufficient to drive such materials in the course of the wind to a distance of several hundred miles; and the finer particles or dust to that of several hundred leagues. We proceed to give a few examples. [*Editor*.

2. *Shower of Ashes in the Archipelago.*

By Capt. William Badily.

December 6, 1631, riding at anchor in the Gulf of Volo, about ten o'clock that night, it began to rain sand or ashes, and continued till two o'clock the next morning. It was about two inches thick on the deck, so that we threw it overboard with shovels, as we did snow the day before. The quantity of a bushel we brought home, and presented to several friends, especially to the masters of the Trinity House. There was no wind stirring when these ashes fell; and they not only fell in the places where we were, but likewise in other parts, as ships were coming from St. John d'Acre to our port; though at that time a hundred leagues from us. We compared the ashes together, and found them both alike.

3. *Shower of Dust that fell on a Ship between Shetland and Iceland; in a Letter from Dr. Robert Whytt, Prof. Med.*

By letters from a passenger on board a ship bound from Leith for Charlestown in South Carolina, it appears that on the night of the 23d or 24th of October last, when the weather was quite calm, a shower of dust fell on the decks, tops and sails of the ship, so that next morning they were covered thick with it. The ship at this time was between Shetland and Iceland, about twenty-five

leagues distant from the former, and which was the nearest land. This shower was probably owing to the great eruption, which happened at mount Hecla in Iceland, in October.

4. *On a new kind of Rain. By the Count de Gioeni, an inhabitant of the third Region of Mount Etna. Translated from the Italian.*

The morning of the 24th inst. (April 1781) exhibited here a most singular phenomenon. Every place exposed to the air was found wet with a coloured cretraceous grey water, which, after evaporating and filtrating away, left every place covered with it to the height of two or three lines; and all the iron-work that was touched by it became rusty. The shower extended from N. $\frac{1}{4}$ N. E. to S. $\frac{1}{4}$ S. W. over the fields, about seventy miles in a right line from the vertex of Etna. There is nothing new in volcanos having thrown up sand, and also stones, by the violent expansive force generated within them, which sand has been carried by the wind to distant regions. But the colour and subtilty of the matter occasioned doubts concerning its origin; which increased from the remarkable circumstance of the water in which it came incorporated; for which reasons some other principle or origin was suspected.

It became therefore necessary by all means to ascertain the nature of this matter, in order to be convinced of its origin, and of the effects it might produce. This could not be done without the help of a chemical analysis. To do this then with certainty, I endeavoured to collect this rain from places where it was most probable no heterogeneous matter would be mixed with it. I therefore chose the plant called Brassica Capitata, which having large and turned-up leaves, they contained enough of this coloured water; many of these I emptied into a vessel, and left the contents to settle till the water became clear. This being separated into another vessel, I tried it with vegetable alkaline liquors and mineral acids; but could observe no decomposition by either. I then evaporated the water, to reunite the substances that might be in solution: and touching it again with the aforesaid liquors, it showed a slight effervescence with the acids. When tried with the syrup of violets, this became a pale green; so that I was persuaded it contained a

calcarous salt. With the decoction of galls no precipitation was produced. The matter being afterwards dried in the shade, it appeared a very subtile, fine earth, of a cretaceous colour, but inert, from having been diluted by the rain.

I next thought of calcining it with a slow fire, and it assumed the colour of a brick. A portion of this being put into a crucible, I applied to it a stronger heat, by which it lost almost all its acquired colour. Again, I exposed a portion of this for a longer time to a very violent heat, from which a vitrification might be expected; it remained however quite soft, and was easily bruised, but returned to its original dusky colour. From the most accurate observations of the smoke from the three calcinations, I could not discover either colour or smell that indicated any arsenical or sulphureous mixture. Having therefore calcined this matter in three portions, with three different degrees of fire, I presented a good magnet to each; it did not act either on the first or second; a slight attraction was visible in many places on the third; this persuaded me, that this earth contains a martial principle in a metallic form, and not in a vitriolic substance.

The nature of these substances then being discovered, their volcanic origin appears; for iron, the more it is exposed to violent calcination, the more it is divided, by the loss of its phlogistic principle; which cannot naturally happen but in the great chimney of a volcano. Calcareous salt, being a marine salt combined with a calcareous substance by means of violent heat, cannot be otherwise composed than in a volcano. As to their dreaded effects on animals and vegetables, every one knows the advantageous use, in medicine, both of the one and the other, and this in the same form as they are thus prepared in the great laboratory of nature. Vegetables, even in flower, do not appear in the least macerated, which has formerly happened from only showers of sand.

How this volcanic production came to be mixed with water may be conceived in various ways. Etna, about its middle regions, is generally surrounded with clouds that do not always rise above its summit, which is 2900 paces above the level of the sea. This matter being thrown out, and descending on the clouds below it, may happen to mix and fall in rain with them in the usual way. It may also be conjectured, that the thick smoke which the

volcanic matter contained might, by its rarefaction, be carried in the atmosphere by the winds, over that tract of country; and then, cooling so as to condense and become specifically heavier than the air, might descend in that coloured rain. I must, however, leave to philosophers, to whom the knowledge of natural agents belongs, the examination and explanation of such phænomena, confining myself to observation and chemical experiments.

P. S. On Friday the 4th of May, about a quarter past three in the afternoon, a slight shock of an earthquake was felt in the country about Etna, which became more sensible at some distance from the mountain; its direction was from north to south. The volcano had continued its flames and explosions; and the night before, a column of smoke, composed of globes as it were piled on each other, had ascended over the crater to double the height of the mountain, as far at least as one could judge at the distance of twenty-two miles, which the vertex is in a right line from this city. This remained the whole night perpendicular, only one of the globes had separated and lengthened out to the westward from the summit. Now and then all the inside of the column, and of the lengthened outpart, became illuminated by electric fire, which was of a deep red colour, and gradually went out again, beginning at the bottom, in about two seconds. The fire has continued on the crater till this day, May 8th, ejecting red-hot masses or stones, which rolling beautifully down the cone, have illuminated this region; some lava has run over from the crater towards the W. N. W. but without having force enough to burst the sides or walls of the volcano.

5. *Surprising Shoal of Pumice-stones found floating on the Sea.*

By John Dove *.

On the 22d of March, 1724-5, at noon, being in the latitude of 35° 36′ south, and longitude 4° 9′ west, with variation 3° 16′ W. they discovered several pumice-stones on the sea; but not expecting any such thing at that distance from the land, the islands Tristan d'Acunha being the nearest, which were judged to bear W. 9° 10′ S. distance 186 leagues, they disputed what it might be; when about one P. M. they took up a piece in a bucket, which confirmed Mr. Dove's opinion of its being pumice-stones. Towards night it was spread all round, as far as could be seen. Next morning the pumice-stones were very thick, in drifts, lying N. N. E. and S. S. W. and extended out of sight from the mast head, increasing as they run to the eastward.

Wednesday the 24th they continued their course E. S. E. 140 miles, the pumice-stones being thicker; so that for sixteen hours some of the drifts were about a cable's length broad, and so thick, they could scarcely see the water between them; and there was much the same breadth between the drifts, with several pumice-stones interspersed. Towards noon, they found the pumice somewhat thinner: latitude 37° 35′ S. and longitude 1° 4′ W.

Thursday the 25th, in the evening, the drifts were near as large as above, but towards next morning they decreased much; so that about noon they were clear of the pumice-stones, several of which were as large as a man's head. They sailed 317 miles since they first discovered them. They lay just in the track for ships outward bound; and all the ships that went out the same year and since, who go so far to the southward, have fallen in with them. In the morning they tried the current, but found none: and no ground at 130 fathoms. At noon, latitude 37° 54′ S. longitude 0° 38′ E. they judged Tristan d'Acunha bore W. 3° 39′ N. Distance 256 leagues, supposing it to lie in latitude 37° 5′ S. longitude 15° 38′ W.

[*Phil. Trans.* 1728.

* We give this curious article a place here, as the pumice-stones must necessarily have fallen down in showers.—EDITOR.

SECTION VIII.

Shower of Fishes.

By Robert Conny.

On Wednesday before Easter, anno 1666, a pasture field at Cranstead, near Wrotham, in Kent, about two acres, which is far from any part of the sea, or branch of it, and a place where are no fish-ponds, but a scarcity of water, was all overspread with little fishes, conceived to be rained down, there having been at that time a great tempest of thunder and rain; the fishes were about the length of a man's little finger, and judged by all who saw them to be young whitings. Many of them were taken up, and showed to several persons. The field belonging to one Ware, a yeoman, who was at that Easter Sessions one of the grand inquest, and carried some of them to the sessions at Maidstone in Kent, and he showed them, among others, to Mr. Lake, a bencher of the Middle Temple, who had one of them, and brought one to London. The truth of it was averred by many that saw the fishes lie scattered all over that field. There were none in the other fields adjoining: the quantity of them was estimated to be about a bushel.

[*Phil. Trans.* 1698.

It is probable that these fishes were absorbed from the surface of the water by the electric suction of a water-spout; or brushed off by the violence of a hurricane. The phænomenon, though surprising, has occurred in various countries; and occasionally in situations far more remote from the coast than that before us *.

[*Editor.*

SECTION VI.

On the Nature of Snow.

1. *Configuration of its Crystals.*

By Dr. Grew.

If Aristotle and Descartes, &c. who have written of meteors, and amongst them of snow, have not given a full account of it, it will

* For the fall of aërolites, or meteoric stones, see chapter xlvi. section vii.

not be needless to inquire further of it. He that will do this, will do it best, not by the pursuit of his fancy in a chair, but with his eyes abroad; where, if we use them well fixed, and with caution, and this in a thin, calm, and still snow, we may by degrees observe; 1st. with M. Descartes and Mr. Hook, that many parts of snow are of a regular figure; for the most part, as it were, so many little rowels or stars of six points; being perfect and transparent ice, as any we see on a pool or vessel of water. On each of these six points are set other collateral points, and those always at the same angles as are the main points themselves. Next, among these irregular figures, though many of them are large and fair; yet, from these taking our first item, many others, alike irregular, but much smaller, may likewise be discovered. Again, among these not only regular, but entire parts of snow, looking still more warily, we shall perceive that there are divers others, indeed irregular, yet chiefly the broken points, parcels, and fragments of the regular ones.—Lastly, that besides the broken parts, there are some others which seem to have lost their regularity, not so much in being broken, as by various winds, first gently thawed, and then frozen into little irregular clumps again.

From hence the true notion and external nature of snow seems to appear, *viz.* that not only some few parts of snow, but originally the whole body of it, or of a snowy cloud, is an infinite mass of icicles regularly figured; that is, a cloud of vapours being gathered into drops, the said drops forthwith descend; on which descent, meeting with a soft freezing wind, or at least passing through a colder region of air, each drop is immediately frozen into an icicle, shooting itself forth into several points on each hand outward from its centre: but still continuing their descent, and meeting with some sprinkling and intermixed gales of warmer air, or in their continual motion and waftage to and fro, touching upon each other, some are a little thawed, blunted, frosted, clumpered, others broken, but the most clung in several parcels together, which we call flakes of snow.

It being known what snow is, we perceive why, though it seems to be soft, yet it is truly hard; because true ice, seeming only to be soft; because on the first touch of the finger on any of its sharp edges or points, they instantly thaw; otherwise they would pierce our fingers like so many lancets. Why again, though snow be

true ice, and so a hard and dense body, yet very light; because of the extreme thinness of each icicle in comparison of its breadth. Also how it is white, not because hard; for there are many soft bodies white; but because consisting of parts all of them singly transparent, but being mixed together appear white; as the parts of froth, glass, ice, and other transparent bodies, whether soft or hard.

Thus much for the external nature of snow; let us next a little inquire into its essential nature. Now if we would make a judgment of this, I think we may best do it by considering what the general figure of snow is, and comparing the same with such regular figures as we see in divers other bodies. As for the figure of snow, it is generally one; *viz.* that which is above described: rarely of different ones, which may be reduced chiefly to two generals, circulars and hexagonals, either simple or compounded together. More rarely, either to be seen of more than six points; but if so, then not of eight or ten, but twelve. Or in single shoots, as so many short slender cylinders, like those of nitre. Or by one of these shoots, as the axle-tree, and touching upon the centre of a pair of pointed icicles, joined together as the two wheels. Or the same hexagonal figure, and of the same usual breadth; but continued in thickness or profundity, like the stone which Boetius calls *Astroïtes*. All these I say are rare, the first described being the general figure*.

[*Phil. Trans.* 1673.

To determine the quantity of water a given quantity of snow is equal to, we have an ingenious article in the same journal from the pen of Mr. Alexander Brice, of Kirknewton, dated May 13, 1766; in which he observes, that, from the end of March 1765 to the end of September of the same year, they had very little rain in that part of Scotland, and less snow in proportion: the rivers were as

* In an article in a subsequent volume by M. J. C. Beckman, we have the following notice of another variety in the form of snow: "On the 1st of March last, there fell an unusual kind of snow, which I considered with more than ordinary attention. It had none of the ordinary figures, but was made up of little pillars, whereof some were tetragonal, some hexagonal, with a neat basis. On the top they were somewhat larger, as the heads of columns are. Considering the whole shape, we thought fit to give it the name of *Nix Columnaris*."

low, through the winter, as they used to be in the middle of summer; springs failed in most places, and brewers and maltsters were obliged, even in winter, to carry their water from a considerable distance.

In the end of March last, they had a fall of snow; and, as he did not remember to have ever read an account of such an experiment, he wished to be able to determine, to what quantity of rain this fall of snow was equal. The snow had been falling from five o'clock the former evening, till ten o'clock next day; about eleven o'clock he measured the depth of the snow, and found it to be 6.2 inches; he then took a stone jug, holding about three English pints, and turned the mouth of it downwards on the snow measured, and where the ground below was smooth, and hard; and by this means he took up all the snow from top to bottom in the jug; this snow he melted by the side of a fire, and the 6.2 inches of snow yielded six-tenths of an inch deep of water in the same jug. After emptying the jug, he dried, and weighed it in a balance, and took up the same quantity of snow in it as before, weighed it again, and found the weight of the snow taken up, and from this weight computed what quantity of water it should have produced, and found that it should have produced 6-10ths of an inch, and 1-20th of an inch more; he then dissolved the snow, and found that it yielded a quantity of water in the bottom of the jug, 6-10ths of an inch deep, as in the former experiment. The difference of 1-20th of an inch in the depth of the water, between the weight and the melting of the snow, was probably owing to an exhalation from the jug, while the snow was melting by the fire, for he observed a steam sometimes rising from it. A greater or less degree of cold, or of wind, while the snow falls, and its lying a longer or shorter time on the ground, will occasion a difference in the weight, and in the quantity of water produced, from a certain number of cubic feet, or inches, of snow; but if he may trust to the above trials, which he endeavoured to perform with care, snow, newly fallen, with a moderate gale of wind, freezing cold, which was the case of the snow he made the trials on, the 27th of March last, will produce a quantity of water equal to 1-10th part of its bulk; or the earth, when covered with snow, ten inches deep, will be moistened by it when melted, or rivers and springs recruited, as much as if a quantity of

rain had fallen that had covered the surface of the earth to the depth of one inch.

[*Phil. Trans.* 1766.

2. *Mode of the Formation of Snow.*

The frequent changes of the weather that have taken place during the last winter *, having induced me to direct my attention to meteorology, I confess, that the manner in which philosophers account for some of the phænomena that occur, is not, to me, altogether satisfactory.

It is not surprising, that electricity (with the immediate agency of which we are so little acquainted) should be resorted to, as the grand agent in all meteorological phænomena. Accordingly we find, that snow, and indeed every variety of weather we experience, is considered to be more or less affected by the electric fluid.

Snow is generally supposed to be the vapours of the atmosphere, disengaged by the electric fluid, and frozen.

But it appears to me, that before we receive so vague an explanation, the following questions might be asked :—

What are the vapours of the atmosphere composed of?

By what laws, and in what manner does the electric fluid act, either in the formation of snow, or as a component part of it?

I shall now offer a few remarks to strengthen a supposition that the electric fluid is not engaged in, or in the least essential to the production or existence of snow.

By an attentive observation of all the circumstances that have attended the fall of snow, during the last winter, I have, in almost every instance, found that is accompanied with, or rather preceded by a change of the wind; and that the wind, previous to the fall of snow, blew from some point between the south and the west; and afterward from some point between the east and the northwest †.

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* 1804.

† If it is observed, that we have sometimes snow, without the wind changing to any of the points above-mentioned, or, even without a visible change to us; yet it does not militate against the following remarks; for it has been observed by aeronauts, that different strata of air blow from opposite points at the same time. Therefore, notwithstanding a south wind may prevail at the surface of the earth, a superior stratum may blow from the north.

Such being the facts, is it not probable, that a change of the wind is the cause of snow?

Now let us examine, whether such a cause will produce such an effect.

The winds that blow from any of the points between the south and the west, by coming from warm climates, and passing over, perhaps, a very large tract of water, where there is a powerful evaporation going on, must possess a very great degree of humidity, and are most commonly of a temperature between 45° and 60° of Fahrenheit.

The winds which blow from any of the points between the east and the north-west, by coming mostly from such high latitudes, and passing over immense fields of ice, where evaporation is undoubtedly greatly impeded, cannot be supposed to contain much water in solution, but must bring with them very great degrees of cold.

Now let us suppose that a north wind of any temperature between 32° and 0° (which it generally is, in superior strata of the atmosphere) meets a south-west wind, as before-mentioned, the consequence will be, that the intense cold which accompanies the former will convert the water with which the latter is impregnated, into ice; and the instantaneous application of cold is probably the reason why snow is produced in what we call flakes; for before the vapour can concentrate itself into large particles, or drops, it is arrested by the intense cold.

In this view, the formation of snow appears to be a beautiful chemical phænomenon; for the warmer air, having a greater affinity for the colder air than it has for the water which is held in solution, the water is disengaged, crystallized by the cold, and precipitated in the form of snow.

It is generally observed, that it is unusually cold for half an hour or an hour before the fall of snow, and warmer afterwards. Might not this be accounted for, by considering that the adverse wind must meet with consistence, in effecting either a union with, or a passage through a stratum of air surcharged with water, and consequently must be in a great degree reflected back again, not in the perpendicular, but as radii from a center, in an oblique direction, part of which must descend to the earth. And it will undoubtedly be warmer, after the stratum of north wind has either

forced a passage through or effected an union with the south-west wind*.

Though I have not, in the preceding observations, considered the electric fluid as at all essential to the production of snow, yet I do not deny the presence of it. That snow contains the electric fluid, cannot be doubted; but it does not follow, that the latter is necessary to the existence of the former. We know of no substance in nature, that is impervious to that subtile fluid; it seems to pervade all bodies with nearly the same facility as caloric. Therefore, though snow indicates electricity, it is probably no more than it has acquired in its passage through an electrified atmosphere.

[*Nicholson's Journal.*

SECTION X.

Snow of a Red Colour.

1. *Descent of Red Snow at Genoa.*

In a communication from Signor Sarotti, the Venetian Resident at Genoa, to the Honourable Mr. Boyle.

On St. Joseph's day, on the mountains called Le Langhe, there fell on the white snow, that lay there before, a great quantity of red, or if you please of bloody snow. From which, being squeezed, there came a water of the same colour.

[*Phil. Tran.* 1678.

Although no mention is here made of any volcanic eruption in the neighbourhood, it is probable that the cause of the colour was owing to some calorific material thrown forth in the course of such a phænomenon. In article 4, of section vii. we have already noticed a descent of coloured rain, evidently deriving its peculiar tincture from such a cause.

In the following article, M. Saussure offers another opinion, or rather several other opinions, for he seems by no means to have satisfied himself upon the subject. [EDITOR.

* The water gives out heat in congelation. Vide Irwine, Black, Crawford, &c.

2. *Snow of a Red Colour found in the Alps.*

When M. de Saussure explored Mount Breven, for the first time, in the year 1760, he found in several places on a declivity snow still remaining, and was not a little surprised to see the surface of it, in various parts, tinged with a very lively red colour. This colour was brightest in the middle of such spots as had their centres more depressed than the edges, or where different plains covered with snow seemed to be joined to each other. When he examined this snow more closely, he remarked that its redness proceeded from a very fine powder mixed with it, and which had penetrated to the depth of two or three inches, but no farther. It did not appear that this powder had come from the higher parts of the mountain, because some of it was found in places at a considerable distance from the rocks and much lower down; and it appeared also that it had not been conveyed thither by the winds, because it was not disposed in stripes or in the form of radii. The most probable conjecture therefore was, that it was a production of the snow itself, or the remains of its partial melting suspended at its surface as in a filtre when the water passed through it. What seemed to favour this conjecture still more, was, that the colour at the edges of the hollow places where little water had sunk down was extremely faint; and, on the other hand, shewed itself stronger in those parts where the greatest quantity of water seemed to have penetrated.

M. de Saussure took a tumbler full of this snow, as he had no other vessel with him, and held it in his hand till the snow melted, when he soon saw the red dust deposit itself at the bottom. Its colour then did not appear so dazzling as before, and when dry it lost it entirely: it decreased also in quantity, so as almost to appear nothing.

Next year M. de Saussure ascended the Breven, and found on it a quantity of the same kind of red snow, some of which he squeezed closely together and put into a large handkerchief, but before he got home it was entirely dissolved by the heat of the sun. It was not, however, on the Breven alone that he discovered snow of this kind; for he found it on all the high mountains of the Alps, about the same season of the year, and in similar situations; so that he was much surprised that authors who had written

respecting the Alps, such as Scheuchzer, had made no mention of it. It is, indeed, true that it is found only in hollows, where the snow lies deep, and at the season of the year when the melting of it has proceeded to a certain degree; for, when none of the snow or when very little of it has been melted, the dust is then in too small quantity to attract the eye; and if the melting has proceeded too far, the whole of the powder has passed through with the water, and it becomes equally invisible. Besides, towards the end of the melting, a great many foreign particles and impurities, conveyed thither by the wind, are mixed with it, so that its colour is no longer distinguishable.

In the year 1778, when M. de Saussure was on mount St. Bernard, he found a great deal of the same kind of snow. He collected as much of it as he possibly could; and Mr. Murrith, an experienced naturalist, collected some of it also; so that they were enabled to make some experiments. On account of its great specific gravity, M. de Saussure treated this red powder as an earth, first with distilled vinegar, but he employed so little that he had no result. He then boiled it in the muriatic acid, and obtained a solution, which, when carefully distilled and filtered, had so brown a colour that he was quite at a loss respecting the nature of this substance. He therefore applied it to the blow-pipe, and observed that it inflamed with a smell like that of burnt vegetables.

This experiment induced M. de Saussure to digest forty grains of the powder in spirit of wine; and having filtered the solution, he found that the residue weighed seven grains less: the spirit of wine had become of a golden yellow colour He then distilled it in a balneum mariæ, and the spirit of wine came off perfectly pure. An oily transparent matter of a golden brown colour, which by the warmth of the balneum mariæ had not become dry, remained at the bottom of the retort. This oily matter had a smell like that of wax, which it emitted also when burning. The deposit, which the spirit of wine had not dissolved, was, in regard to its extractive part, also inflammable; and the ashes which remained after it was burnt, though they did not seem alkaline, were refused by the blow-pipe into a porous kind of greenish glass.

These experiments seem to prove that this powder was a vegetable substance, and probably the farina of some flower. M. de Saussure was acquainted with no plant in Swisserland that pro-

Engraved by H. R. Cook from a Drawing by Craig.

for the Gallery of Nature & Art.

FALL OF AN AVALANCHE,

near the Glacier of Grindelwalde.

London, Published by R. H. Rose, 43 Holborn Hill, May 2, 1820.

duced red farina in such abundance as to tinge the snow of the Alps red; especially when it is considered that a great deal of it must be lost before it can reach the spots where the red snow is found. But the action of light, perhaps, may first give it its red colour; and in regard to its specific gravity, that is not surprising, as by its long continuance on the snow it must, on account of the repeated slow meltings, receive such an accumulation of particles as to become dense and heavy.

M. de Saussure communicated his discovery to M. Bonnet, who advised him to examine the powder with a microscope, in order to see whether it exhibited the appearance of the farina of flowers. He did so with the greatest care and the best glasses, but he could not discover the least regularity in its form.

Though M. de Saussure found this powder in different places on the Alps, he however asks, whether it be very common, and whether it be found on the high mountains in different countries and different climates, such, for example, as the Cordilleras? These questions deserve certainly to be examined; and though it be probable that this powder consists of the farina of flowers, it is not altogether impossible that it may be an earth separated by the snow itself, and possessing some inflammable properties called forth by the immediate action of the light and heat of the sun, which shines with so much liveliness in the pure air of these elevated regions.

[*Voyages dans les Alpes. Tom. III.—Phil. Mag.*

SECTION XI.

Avalanches, or falling Masses of detached and incumbent Snow-heaps from the Summits of lofty Mountains.

These vast accumulations are frequently to be met with in the Alps; and their fall is often accompanied with utter ruin to various cottages that lie below, which are often buried and lost beneath the overwhelming weight. It is not many years since an instance occurred in which a small family was imprisoned for more than a fortnight under an avalanche of this kind, several hundred feet in depth*. During the whole of this period they continued

* In 1710 a storm of snow fell with so much violence as to destroy 7000 Swedes in their march against Drontheim. [*Young's Nat. Phil.*

in utter darkness, and supported themselves entirely by the nourishment afforded them by a milch ass, which was fortunately buried with them. The cottage was destroyed by the crush, and the family would have been destroyed also, but from the strength of a powerful beam that supported the roof in the very part of it to which they retreated.

These catastrophes, however, are not peculiar to the Alps: they are often experienced in Switzerland, several parts of Germany, and Italy; and still more frequently in Savoy, where they are also larger and more dreadful. Somé avalanches, by the tract they leave behind, are found to be above an hundred yards in diameter. In the year 1695, one of them fell upon the village of Valmedia, and destroyed eleven houses, together with as many barns and stables, so entirely, that there scarcely remained one stone upon another. The noise they make resembles a long and loud clap of thunder, and is heard among the echoing rocks and mountains at several leagues distance; and yet so rapid is their motion, that passengers have seldom time to avoid them.

The following description from the elegant pen of Mrs. Charlotte Smith has been often realised:

Where cliffs arise by winter crown'd,
And through paık groves of pine around,
Down the deep chasms, the snow-fed torrents foam,
Within some hollow, shelter'd from the storms,
The peasant of the Alps his cottage forms,
And builds his humble, happy home.

But absent from this calm abode,
Dark thunder gathers round his road,
Wild raves the wind, the arrowy lightnings flash,
Returning quick the murmuring rocks among,
His faint heart trembling as he winds along;
Alarm'd! he listens to the crash

Of rifted ice!—Oh, man of woe!
O'er his dear cot—a mass of snow,
By the storm sever'd from the cliff above,
Has fallen—and buried in its marble breast
All that for him—lost wretch—the world possest,
His home, his happiness, his love!

Aghast the heart-struck mourner stands,
Glaz'd are his eyes—convuls'd his hands,

O'erwhelming anguish checks his labouring breath ;
Crush'd by despair's intolerable weight,
Frantic, he seeks the mountain's giddiest height,
And headlong seeks relief in death.

One of the most minute and extraordinary accounts, however, of this fearful destruction, which have yet been published, occurs in the following article of the Philosophical Transactions, communicated by professor Bruni, of Turin, to Henry Baker, Esq. F.R.S. of the date of March 19, 1755 ; and is supported by the official testimony of the Intendant of the town and province of Cuneo.

In the neighbourhood of Demonte, as in the upper valley of Stura, on the left hand, about an hour and half distant from the road leading to the castle of Demonte, towards the middle of the mountain, there were some houses in a place called Bergemoletto, which on the 19th of March, in the morning, (there being then a great deal of snow) were entirely overwhelmed and ruined by two vast bodies of snow, that tumbled down from the upper mountain. All the inhabitants were then in their houses, except one Joseph Rochia, a man of about 50, who with his son, a lad of fifteen, were on the roof of his house, endeavouring to clear away the snow, which had fallen without any intermission for three preceding days. Whence perceiving a mass of snow tumbling down towards them from the mountain above, they had but just time to get down and flee, when, looking back, they perceived the houses were all buried under the snow. Thus twenty-two persons were buried under this vast mass, which was 60 English feet in height, insomuch that many men, who were ordered to give them all possible assistance, despaired of being able to do them the least service.

After five days, Joseph Rochia having recovered of his fright, and being able to work, got upon the snow, with his son, and two brothers of his wife's, to try if they could find the exact place under which his house and stable were buried ; but though many openings were made in the snow, they could not find the desired place. However the month of April proving very hot, the snow beginning to soften, and indeed a great deal of it melted, this unfortunate man was again encouraged to use his best endeavours to recover the effects he had in the house, and to bury the remains of

his family. He therefore made new openings in the snow, and threw earth into them, which helps to melt the snow and ice. On the 24th of April the snow was greatly diminished, and he conceived better hopes of finding out his house, by breaking the ice, which was six feet thick, with iron bars, and observing the snow to be softer underneath the ice, he thurst down a long pole, and thought it touched the ground; but the evening coming on he proceeded no further.

His wife's brothers, who lived at Demonte, went with Joseph and his neighbours, to work upon the snow, where they made another opening, which led them to the house they searched for; but finding no dead bodies in its ruins, they sought for the stable, which was about 240 feet distant, and having found it, they heard a cry of "Help, my dear brother." Being greatly surprised as well as encouraged by these words, they laboured with all diligence till they had made a large opening, through which the brothers and husband immediately went down, where they found still alive the wife about forty-five, the sister about thirty-five, and a daughter about thirteen years old. These women they raised on their shoulders to men above, who drew them up, as it were from the grave, and carried them to a neighbouring house; they were unable to walk, and so wasted that they appeared like mere shadows. They were immediately put to bed, and nourishments administered. Some days after the intendant came to see them, and found the wife still unable to rise from her bed, or use her feet, from the intense cold she had endured, and the uneasiness of the posture she had been in. The sister, whose legs had been bathed with hot wine, could walk with some difficulty; and the daughter needed no further remedies, being quite recovered.

On the intendant's interrogating the women, they told him, that their appetite was not yet returned; that the little food they had eaten (excepting broths and gruels) lay heavy on their stomachs, and that the moderate use of wine had done them great good: they also gave him the account that follows: That on the morning of the 19th of March they were in the stable with a boy six years old, and a girl about thirteen: in the same stable were six goats, one of which having brought forth two dead kids the evening before, they went to carry her a small vessel full of gruel: there were also an ass and five or six fowls. They were sheltering

themselves in a warm corner of the stable, till the church bell should ring, intending to attend the service.

That the wife wanting to go out of the stable to kindle a fire in the house for her husband, who was then clearing away the snow from the top, she perceived a mass of snow breaking down towards the east, on which she went back into the stable and shut the door. In less than three minutes they heard the roof break over their heads, and part of the ceiling of the stable. The sister advised her to get into the rack and manger, which she did. The ass was tied to the manger, but got loose by kicking and struggling, and though it did not break the manger, it threw down the little vessel, which the sister took up, and used afterwards to hold the melted snow, which served them to drink.

Very fortunately the manger was under the main prop of the stable, and resisted the weight of the snow. Their first care was to know what they had to eat: the sister said, she had in her pocket fifteen white chesnuts: the children said they had breakfasted, and should want no more that day. They remembered there were thirty or forty loaves in a place near the stable, and endeavoured to get at them, but were not able, by reason of the vast quantity of snow. On this they called out for help as loudly as they possibly could, but were heard by nobody. The sister came again to the manger, after she had tried in vain to come at the loaves, and gave two chesnuts to the wife, also eating two herself, and then drank some snow water. All this while the ass was very restless and continued kicking, and the goats bleated very much, but soon after they heard no more of them. Two of the goats however were left alive, and were near the manger; they felt them very carefully, and knew by so doing that one of them was big, and would kid about the middle of April; the other gave milk, with which they preserved their lives. The women affirmed, that during all the time they were thus buried, they saw not one ray of light; yet for about twenty days they had some notion of night and day; for when the fowls crowed, they imagined it was break of day: but at last the fowls died.

The 2d day, being very hungry, they ate all the remaining chesnuts, and drank what milk the goat yielded, which for the first days was near a quart a day, but the quantity decreased gradually. The third day, being very hungry, they again endeavoured

to get to the place where the loaves were, near the stable, but they could not penetrate to it through the snow. They then resolved to take all possible care to feed the goats, as very fortunately over the ceiling of the stable, and just above the manger, there was a hayloft, with a hole through which the hay was put down into the rack. This opening was near the sister, who pulled down the hay and gave it to the goats as long as she could reach it, which when she could no longer do, the goats climbed upon her shoulders, and reached it themselves.

On the sixth day the boy sickened, complaining of most violent pains in the stomach, and his illness continued six days, on the last of which he desired his mother, who all this time had held him in her lap, to lay him at his length in the manger, where he soon after died. In the mean time the quantity of milk given by the goat diminished daily, and the fowls being dead, they could no more distinguish night and day; but according to their calculation the time was near when the other goat should kid, which as they computed would happen about the middle of April; which at length happened accordingly. They killed the kid, to save the milk for their own subsistence. Whenever they called this goat, it would come and lick their faces and hands, and gave them every day a quart of milk.

They say, during all this time hunger gave them but little uneasiness, except on the first five or six days: that their greatest pain was from the extreme coldness of the melted snow water, which fell on them, and from the stench of the dead ass, dead goats, fowls, from lice, &c. but more than all from the very uneasy posture they were obliged to continue in: for though the place in which they were buried was twelve English feet long, eight wide, and five high, the manger in which they sat squatting against the wall, was no more than three feet four inches broad. For thirty-six days they had no evacuation by stool after the first days: the melted snow water, which after some time they drank without doing them harm, was discharged by urine. The mother said she had never slept, but the sister and daughter declared they slept as usual. The mother and sister say, that on the day they were buried their monthly evacuations were upon them, but they had not the least sign of them afterwards.

[*Phil. Trans. Abr.* 1756.

SECTION XII.

General Nature of Hail.

We have already touched upon the formation of hail, in Section 1, of the present chapter; and shall only add a few incidental remarks. M. Lichtenberg, in the Hanover Magazine for January 1773, conceives that hail depends on electricity, perhaps as promoting evaporation and cold. He observes that it very seldom hails at night: that, in winter, snow is much more common than hail; that it often snows or rains for some days; and then hails with thunder; and that hail often attends volcanic explosions*. Most of these circumstances are easily understood, if we consider that much of the cold which congeals the hail is probably produced by evaporation.

Aldini carried the opinion of Lichtenberg so far as to conceive that snow also derives its form from electricity. The observation, however, upon which his hypothesis is founded, has been denied by Von Arnim.

Franklin suspects that hail is formed in a very cold region, high in the atmosphere†. But this is not the most popular hypothesis.

In the ensuing section we shall select a few well-accredited accounts of hail-stones of great bulk and weight. The largest of which we have any notice is recorded by Gilbert ‡, but from news-paper authority only. It fell in Hungary in 1803, and was so heavy that eight men were incapable of lifting it. In the Pyrennees, several of twenty-three ounces, avoirdupois, are well known to have fallen in 1784; a paper written by the Abbé Maury was read before the Royal Society, Nov. 22, 1798, in which he announces the fall of hail-stones or pieces of ice in Germany, from half an inch diameter to eight pounds weight.

[Editor.

* See upon this subject Chap. xlvi. sect. viii. on Meteoric Stones.

† Manchester Memoirs, ii. 857. ‡ xvi. 75.

SECTION XIII.

Violent Hail-storms, or accompanied with Stones of unusual Size.

1. *On the Coast of Suffolk.*

By Dr. Nath. Fairfax.

JULY 17, 1666, about ten in the forenoon, there fell a violent storm of hail about the coast towns of Suffolk. The hail was small near Yarmouth; but at Seckford-hall, one hail-stone was found by measure to be nine inches about; one at Melton eight inches about; at Snape-bridge twelve inches round. A lady of Friston Hall, putting one of them into a balance, found it to weigh 12*s.* 6*d*. Several persons of good credit in Aldborough affirmed that some hail-stones were full as large as turkeys' eggs. A carter had his head broken by them through a stiff felt hat; in some places his head bled, in others bumps arose; the horses were so pelted that they hurried away his cart beyond all command. The hail-stones seemed all white, smooth without, shining within.

[*Phil. Trans.* 1667.

2. *At Lisle in Flanders.*

THERE fell in this city, May 25, N. S. 1686, hail-stones which weighed from a quarter of a pound to a pound weight and more. One among the rest was observed to contain a dark brown matter in the middle, and being thrown into the fire, it gave a very great report. Others were transparent, which melted before the fire immediately. This storm passed over the citadel and town, and left not a whole glass in the windows on the windward side. The trees were broken, and some beat down, and the partridges and hares killed in abundance.

[*Id.* 1693.

3. *In the Neighbourhood of Chester, communicated in a Letter from Mr. Halley.*

THE vapour that disposed the aqueous parts thus to congeal, came with a south-west wind out of Carnarvonshire, passing near Snowdon with a horrid black cloud, attended with frequent light-

nings and thunder. I hear no further of it westward than out of Denbighshire, where it left St. Asaph to the right, and did much damage between it and the sea, breaking all the windows on the weather side, killing poultry, lambs, and a stout dog; and in the north part of Flintshire several people had their heads broken, and were grievously bruised in their bodies. From Flintshire it crossed over the arm of the sea that comes up to Chester, and was only felt in Cheshire, at the very N. W. corner of the peninsula, called Wirall, between the Æstuaria of Chester and Liverpool, at a town called West Kirkby, where it hailed only for three minutes, it being on the extreme point of it on the right hand, but it thundered dreadfully, and was here about three in the afternoon; but the main body of it fell upon Lancashire, in a right line from Ormskirk to Blackburn, on the borders of Yorkshire; the breadth of the cloud was about two miles, within which compass it did incredible damage, killing all sorts of fowls and small creatures, and scarcely leaving any whole panes in any of the windows where it passed; but, which is worse, it ploughed up the earth, and cut off the blade of the green corn, so as utterly to destroy it, the hail-stones burying themselves in the ground; and the bowling-greens, where the earth was any thing soft, were quite defaced, so as to be rendered unserviceable for a time. The hail-stones, some of which weighed five ounces, were of different forms, some round, some half round, some smooth, others embossed and crenulated, like the foot of a drinking-glass, the ice very transparent and hard, but a snowy kernel was in the middle of most of them, if not all; the force of their fall showed they fell from a great height. What I take to be most extraordinary in this phenomenon is, that such a sort of vapour should continue undispersed for so long a tract, as above 60 miles together, and in all the way of its passage occasion so extraordinary a coagulation and congelation of the watery clouds, as to increase the hail-stones to so vast a bulk in so short a space as that of their fall.

In a subjoined account of the same storm we are told as follows, though the correspondent does not mention the place he writes from :—

"We had only the extreme skirt of the shower here, and there fell not above one hundred hail-stones in our court, but they were much larger and harder than we had ever seen. Some measured

about five inches round. Scarcely any of them was so little as a musket bullet, but most of them far larger, and of that figure. Some, indeed, as large as hens' eggs, and of half a pound weight. Many sea-fowl and land-fowl were killed."

[*Phil. Trans.* 1697.

4. *In Hertfordshire.*

By Mr. Robert Taylor.

At Hitchin, on Tuesday, May 4, 1767, about nine in the morning, it began to lighten and thunder extremely, with some great showers between. It continued till about two in the afternoon, when on a sudden a black cloud arose in the S. W. the wind being E. and blowing hard; then fell a sharp shower, with some hail-stones, which measured seven or eight inches about. But the extremity of the storm fell about Offley, where a young man was killed, and one of his eyes struck out of his head; his body was all over black with the bruises; another person nearer to Offley escaped with his life, but much bruised. In the house of Sir John Spencer, 7000 quarries of glass were broken, and great damage done to all the neighbouring houses thereabouts. The hail fell in such vast quantities, and so great, that it tore up the ground, split great oaks and other trees, in great numbers; it cut down great fields of rye, as with a scythe, and has destroyed several hundred acres of wheat, barley, &c. insomuch that they plough it up, and sow it with oats: the tempest was such when it fell, that in four poles of land, from the hills near us, it carried away all the staple of the land, leaving nothing but the chalk. I was walking in my garden, which is very small, about 30 yards square, and before I could get out, it took me to my knees, and was through my house before I could get in, which was in the space of a minute, and went through all like a sea, carrying all wooden things like boats on the water, the greatest part of the town being under this misfortune. The size of the hail-stones is almost incredible; they have been measured from 1 to 13 and 14 inches about. Their figures various, some oval, others round, others pointed, some flat*.

Ibid. 1697.

* There is a subjoined account of a similar storm in the same county, in June 1697, during which the stones that fell, upon being measured, proved above nine inches in compass. [Editor.

CHAP. XL.

ON WINDS OR ATMOSPHERICAL CURRENTS.

SECTION I.

General Remarks on the Nature and Origin of Winds, Trade-winds, Monsoons, partial Winds, and Hurricanes.

No phenomenon in meteorology has more engaged the attention of men of observation than the winds, or those currents which so often disturb the tranquillity of the atmosphere. The subject is not only curious, but highly interesting; for upon their direction and force navigation in a great measure depends; the temperature of climates is greatly influenced by them; and they are absolutely necessary to preserve the salubrity of the atmosphere. To be acquainted with the laws by which they are regulated, and to be able to calculate beforehand the consequences of these laws, has been in every age the eager wish of philosophers. But whether it has been, owing to an improper method of studying this subject, or to its lying beyond the reach of the human faculties, philosophers have not made that progress in it which the sanguine imaginations of some individuals led them to expect. Many discoveries, indeed, have been made; and from the numbers and the genius of the philosophers at present engaged in this study, others equally important may be expected. But, notwithstanding this, many of the phenomena remain unexplained, and a rational and satisfactory theory seems still beyond our reach. I shall in this section give as complete a detail as possible of the natural history of the winds in the different parts of the world, and then consider how they may be explained.

As the winds are much more regular between the tropics than in the temperate zones, it will be proper in the first place to begin with them.

In those parts of the Atlantic and Pacific Oceans which lie nearest the equator, there is a regular wind during the whole year, called the *trade-wind*. On the north side of the equator it blows

from the north-east, varying frequently a point or two towards the north or east; and on the south side of it, from the south-east, changing sometimes in the same manner towards the south or east. The space included between the second and fifth degree of north latitude is the internal limit of these two winds. There the winds can neither be said to blow from the north nor the south; calms are frequent, and violent storms. This space varies a little in latitude as the sun approaches either of the tropics.—In the Atlantic Ocean the trade-winds extend farther north on the American than on the African coast; and as we advance westward, they become gradually more easterly, and decrease in strength*. Their force diminishes likewise as we approach their utmost boundaries. It has been remarked also, that as the sun approaches the tropic of Cancer, the south-east winds become gradually more southerly, and the north-east winds more easterly: exactly the contrary takes place when the sun is approaching the tropic of Capricorn †.

The trade-wind blows constantly in the Indian Ocean from the 10th degree of south latitude to near the 30th: but to the northward of this the winds change every six months, and blow directly opposite to their former course. These regular winds are called *monsoons*, from the Malay word *moossin*, which signifies "a season ‡." When they shift their direction, variable winds and violent storms succeed, which last for a month, and frequently longer; and during that time it is dangerous for vessels to continue at sea.

The monsoons in the Indian Ocean may be reduced to two, one on the north and another on the south side of the equator, which extend from Africa to the longitude of New Holland and the east coast of China, and which suffer partial changes in particular places from the situation and inflection of the neighbouring countries.

1. Between the 3d and 10th degrees of south latitude the south-east trade-wind continues from April to October; but during the rest of the year the wind blows from the north-west §. Between Sumatra and New Holland this monsoon blows from the south during our summer months, approaching gradually to the south-east as we advance towards the coast of New Holland; it changes

* Dr. Halley, Phil. Trans. Abr. vol. ii. p. 134. † Ibid.

‡ Forest's Voyage, p. 95. § Dr. Halley, Phil. Trans. Abr. vol. ii. p. 136.

about the end of September, and continues in the opposite direction till April *. Between Africa and Madagascar its direction is influenced by the coast; for it blows from the north-east from October to April, and during the rest of the year from the south-west †.

2. Over all the Indian Ocean, to the northward of the 3d degree of south latitude, the north-east trade-wind blows from October to April, and a south-west wind from April to October ‡. From Borneo, along the coast of Malacca and as far as China, this monsoon in summer blows nearly from the south, and in winter from the north by east §. Near the coast of Africa, between Mozambique and Cape Guardefan, the winds are irregular during the whole year, owing to the different monsoons which surround that particular place. Monsoons are likewise regular in the Red Sea; between April and October they blow from the north-west, and during the other months from the south-east, keeping constantly parallel to the coast of Arabia ‖.

Monsoons are not altogether confined to the Indian Ocean; on the coast of Brazil, between Cape St. Augustine and the island of St. Catherine, the wind blows between September and April from the east or north-east, and between April and September from the south-west ¶. The bay of Panama is the only place on the west side of a great continent where the wind shifts regularly at different seasons: there it is easterly between September and March; but between March and September it blows chiefly from the south and south-west.

Such in general is the direction of the winds in the torrid zone all over the Atlantic, Pacific, and Indian Oceans; but they are subject to particular exceptions, which it is proper to enumerate. On the coast of Africa, from Cape Bayador to Cape Verde, the winds are generally north-west; from hence to the island of St. Thomas near the equator they blow almost perpendicular to the shore, bending gradually as we advance southwards, first to the

* Dr. Halley, Phil. Trans. Abr. vol. ii. p. 136.

† Bruce's Travels, vol. i. p. 459.

‡ Dr. Halley, Phil. Trans. Abr. vol. ii. p. 156.

§ Dr. Halley, ibid.

‖ Bruce's Travels, vol. i. ch. 4.

¶ Sir Walter Raleigh's Voyage. Forest's Voyage, p. 97.

west and then to the south-west *. On the coast of New Spain likewise, from California to the bay of Panama, the winds blow almost constantly from the west or south-west, except during May, June, and July, when land-winds prevail, called by the Spaniards *popogayos*. On the coast of Chili and Peru †, from 20 or 30 degrees south latitude to the equator, and on the parallel coast of Africa, the wind blows during the whole year from the south, varying according to the direction of the land towards which it inclines, and extending much farther out to sea on the American than the African coast. The trade-winds are also interrupted sometimes by westerly winds in the Bay of Campeachy and the Bay of Honduras.

As to the countries between the tropics, we are too little acquainted with them to be able to give a satisfactory history of their winds.

In all maritime countries between the tropics of any extent, the wind blows during a certain number of hours every day from the sea, and during a certain number towards the sea from the land; these winds are called the *sea* and *land breezes*. The sea-breeze generally sets in about ten in the forenoon, and blows till six in the evening; at seven the land-breeze begins, and continues till eight in the morning, when it dies away ‡. During the summer the sea-breeze is very perceptible on all the coasts of the Mediterranean Sea §, and even sometimes as far north as Norway ‖.

In the island of St. Lewis on the coast of Africa, in 16° north latitude, and 16 west longitude, the wind during the rainy season, which lasts from the middle of July to the middle of October, is generally between the south and east; during the rest of the year it is for the most part east or north-east in the morning; but as the sun rises, the wind approaches gradually to the north, till about noon it gets to the west of north, and is called a *sea-breeze*. Sometimes it shifts to the east as the sun descends, and continues there during the whole night. In February, March, April, May,

* Dr. Halley, Phil. Trans. Abr. vol. 2, p. 136.

† Sir Walter Raleigh's Voyage.—Dr. Garden, Phil. Trans. Abr. vol. ii. p. 132.

‡ Marden's Hist. of Sumatra, p. 17.—Buffon's Nat. Hist. vol. i. p. 385.

§ Volney's Travels.

‖ Pontoppiddan's Natural History of Norway.

and June, it blows almost constantly between the north and west*. In the island of Balama, which lies likewise on the west coast of Africa, in the 11th degree of north latitude, the wind during nine months of the year blows from the south-west; but in November and December a very cold wind blows from the north-east†.

In the kingdom of Bornou, which lies between the 16th and 20th degree of north latitude, the warm season is introduced about the middle of April by sultry winds from the south-east, which bring along with them a deluge of rain‡. In Fezzan, which is situated about the 25th degree of north latitude and the 35th degree of east longitude, the wind from May to August blows from the east, south-east, or south-west, and is intensely hot §.

In Abyssinia the winds generally blow from the west, north-west, north, and north-east. During the months of June, July, August, September, and October, the north and north-east winds blow almost constantly, especially in the morning and evening; and during the rest of the year they are much more frequent than any other winds ||.

At Calcutta, in the province of Bengal, the wind blows during January and February from the south-west and south; in March, April, and May, from the south; in June, July, August, and September, from the south and south-east; in October, November, and December, from the north-west ¶. At Madras the most frequent winds are the north and north-east. At Tivoli in St. Domingo, and at Iles de Vaches, the wind blows oftenest from the south and south-east**. From these facts it appears, that in most tropical countries with which we are acquainted, the wind generally blows from the nearest ocean, except during the coldest months, when it blows towards it.

In the temperate zones the direction of the wind is by no means so regular as between the tropics. Even in the same degree of latitude we find them often blowing in different directions at the same time; while their changes are frequently so sudden and so

* Dr. Schotte, Phil. Trans. vol. lxx. art. 25.

† P. Beaver, Esq. See Map in Wadstrom's Essay on Colonization.

‡ African Association, p. 200. § Ibid.

|| Bruce's Travels, vol. iv. p. 651.

¶ Asiatic Researches, vols. i. and ii. Append.

** P. Cotte, Jour. de Phys. 1791.

capricious, that to account for them has hitherto been found impossible. When winds are violent, and continue long, they generally extend over a large tract of country: and this is more certainly the case when they blow from the north or east than from any other points *. By the multiplication and comparison of Meteorological Tables, some regular connection between the changes of the atmosphere in different places may in time be observed, which will at last lead to a satisfactory theory of the winds. It is from such tables chiefly that the following facts have been collected.

In Virginia the prevailing winds are between the south-west, west, north, and north-west; the most frequent is the south-west, which blows more constantly in June, July, and August, than at any other season. The north-west winds blow most constantly in November, December, January, and February †. At Ipswich in New England the prevailing winds are also between the south-west, west, north, and north-east; the most frequent is the north-west ‡. But at Cambridge, in the same province, the most frequent wind is the south-east §. The predominant winds at New York are the north and west ||: and in Nova Scotia north-west winds blow for three-fourths of the year ¶. The same wind blows most frequently at Montreal in Canada; but at Quebec the wind generally follows the direction of the River St. Lawrence, blowing either from the north-east or south-west **. At Hudson's bay westerly winds blow for three-fourths of the year: the north-west wind occasions the greatest cold, but the north and north-east are the vehicles of snow ††.

It appears from these facts, that westerly winds are most frequent over the whole eastern coast of North America; that in the southern provinces south-west winds predominate; and that the north-west become gradually more frequent as we approach the frigid zone.

In Egypt, during part of May, and during June, July, August, and September, the wind blows almost constantly from the north, vary-

* Derham's Physico-Theology, ch. ii.

† Jefferson's Virginia, p. 123.—Trans. Philad. ii. art. 10.

‡ Trans. Amer. Acad. i. 336. § M. Cotte, Jour. de Phys. 1791.

|| Ibid. ¶ Present State of Nova Scotia and Canada, p. 38.

** Cotte, Jour de Phys. 1791.

†† Pennant's Suppl. to Arctic Zool. p. 41.

ing sometimes in June to the west, and in July to the west and the east; during part of September, and in October and November, the winds are variable, but blow more regularly from the east than any other quarter; in December, January, and February, they blow from the north, north-west, and west; towards the end of February they change to the south, in which quarter they continue till near the end of March; during the last days of March and in April they blow from the south-east, south, and south-west, and at last from the east; and in this direction they continue during a part of May *.

In the Mediterranean the wind blows nearly three-fourths of the year from the north; about the equinoxes there is always an easterly wind in that sea, which is generally more constant in spring than in autumn †. These observations do not apply to the Gut of Gibraltar, where there are seldom any winds except the east and the west. At Bastia, in the island of Corsica, the prevailing wind is the south-west ‡.

In Syria the north wind blows from the autumnal equinox to November; during December, January, and February, the winds blow from the west and south-west; in March they blow from the south, in May from the east, and in June from the north. From this month to the autumnal equinox the wind changes gradually as the sun approaches the equator; first to the east, then to the south, and lastly to the west §. At Bagdad the most frequent winds are the south-west and north-west; at Pekin, the north and the south ||; at Kamtschatka, on the north-east coast of Asia, the prevailing winds blow from the west ¶.

In Italy the prevailing winds differ considerably according to the situation of the places where the observations have been made: at Rome and Padua they are northerly, at Milan easterly **. All that we have been able to learn concerning Spain and Portugal is, that on the west coast of these countries the west is by far the most common wind, particularly in summer; and that at Madrid the wind is north-east for the greatest part of the summer, blowing

* Volney's Travels, i. 58.

† Ibid. i. 59 and 65.

‡ Cotte, Jour. de Phys. 1791.

§ Volney's Travels, i. 326.

|| Cotte, Ibid.

¶ Pennant's Arctic Zool. p. cxiii.

** Cotte, Jour. de Phys. 1791.

almost constantly from the Pyrennean mountains *. At Berne in Switzerland the prevailing winds are the north and west; at St. Gottard, the north-east; at Lausanne, the north-west and south-west †.

Father Cotte has given us the result of observations made at eighty-six different places of France †; from which it appears, that along the whole south coast of that kingdom, the wind blows most frequently from the north, north-west, and north-east; on the west coast, from the west, south-west, and north-west; and on the north coast, from the south-west: that in the interior parts of France the south-west wind blows most frequently in eighteen places; the west wind in fourteen; the north in thirteen; the south in six; the north-east in four; the south-east in two; the east and north-west each of them in one. On the west coast of the Netherlands, as far north as Rotterdam, the prevailing winds are probably the south-west, at least this is the case at Dunkirk and Rotterdam †. It is probable also that along the rest of this coast, from the Hague to Hamburg, the prevailing winds are the north-west, at least these winds are the most frequent at the Hague and at Franeker †. The prevailing wind at Delft is the south-east; and at Breda the north and the east †.

In Germany the east wind is most frequent at Gottingen, Munich, Weissemburgh, Dusseldorf, Saganum, Erford, and at Buda in Hungary; the south-east at Prague and Wurtzburg; the north-east at Ratisbon; and the west at Manheim and Berlin †.

From an average of ten years of the register kept by order of the Royal Society, it appears that at London the wind blows in the following order:

Winds.	Days.	Winds.	Days.
South-west	112	South-east	32
North-east	58	East	26
North-west	50	South	18
West	53	North	16

It appears from the same register, that the south-west wind blows at an average more frequently than any other wind during every

* Bohun's Hist. of Winds, p. 116. † Cotte, Jour. de Phy. 1791.

month of the year, and that it blows longest in July and August; that the north-east blows most constantly during January, March, April, May, and June, and most seldom during February, July, September, and December; and that the north-west wind blows oftener from November to March, and more seldom during September and October than any other months. The south-west winds are also most frequent at Bristol, and next to them are the north-east *.

The following Table of the winds at Lancaster has been drawn up from a register kept for seven years at that place †.

Winds.	Days.	Winds.	Days.
South-west	92	South-east	35
North-east	67	North	30
South	51	North-west	26
West	47	East	17

The following Table is an abstract of nine years observations made at Dumfries by Mr. Copland ‡.

Winds.	Days.	Winds.	Days.
South	82½	North	36½
West	69	North-west	25½
East	68	South-east	18½
South-west	50½	North-east	14½

The following Table is an abstract of seven years observations made by Dr. Meek at Cambuslang near Glasgow §.

Winds.	Days.	Winds.	Days.
South-west	174	North-east	104
North-west	40	South-east	47

It appears from the register from which this Table was extracted that the north-east wind blows much more frequently in April, May, and June, and the south-west in July, August, and September, than at any other period. The south-west is by far the most fre-

* Phil. Trans. lxvi. 2.

† Manchester Trans. iv. 234.

‡ Ibid.

§ Statistical Account of Scotland, v. 245.

quent wind all over Scotland, especially on the west coast. At Saltcoats in Ayrshire, for instance, it blows three-fourths of the year; and along the whole coast of Murray, on the north-east side of Scotland, it blows for two-thirds of the year. East winds are common all over Great Britain during April and May; but their influence is felt most severely on the eastern coast.

The following Table exhibits a view of the number of days during which the westerly and easterly winds blow in a year at different parts of the island. Under the term *westerly* are included the north-west, west, south-west, and south; the term *easterly* is taken in the same latitude.

Years of Observ.	Places.	Wind.	
		Westerly.	Easterly.
10	London	233	132
7	Lancaster	216	149
51	Liverpool*	190	175
9	Dumfries	227·5	137·5
10	Branxholm, 44 miles south-west of Berwick †	232	133
7	Cambuslang	214	151
8	Hawkhill, near Edinburgh ‡	229·5	135·5
	Mean	220·3	144·7

In Ireland the south-west and west are the grand trade-winds, blowing most in summer, autumn, and winter, and least in spring. The north-east blows most in spring, and nearly double to what it does in autumn and winter. The south-east and north-west are nearly equal, and are most frequent after the south-west and west §.

At Copenhagen the prevailing winds are the east and south-east; at Stockholm, the west and north ‖. In Russia, from an average of a register of sixteen years, the winds blow from November to April in the following order:

	W.	N.W.	E.	S.W.	S.	N.E.	N.	S.E.
Days	45	26	23	22	20	19	14	12

* Manchester Trans. iv. † Edin. Trans. i. 203. ‡ Ibid.

§ Rutty's Hist. of the Weather, &c. in Dublin.

‖ Cotte, Jour. de Phys. 1791.

And during the other six months,

	W.	N.W.	E.	S.W.	S.	N.E.	N.	S.E.
Days	27	27	19	24	22	15	32	18

The west wind blows during the whole year 72 days; the north-west 53; the south-west and north 56 days each. During summer it is calm for 41 days, and during winter for 21 *. In Norway the most frequent winds are the south, the south-west, and south-east. The wind at Bergen is seldom directly west, but generally south-west or south-east; a north-west, and especially a north-east wind, are but little known there †.

From the whole of these facts, it appears that the most frequent winds on the south coasts of Europe are the north, the north-east, and north-west; and on the western coast, the south-west: that in the interior parts which lie most contiguous to the Atlantic ocean, south-west winds are also most frequent; but that easterly winds prevail in Germany. Westerly winds are also most frequent on the north-east coast of Asia.

It is probable that the winds are more constant in the south temperate zone, which is in a great measure covered with water, than in the north temperate zone, where their direction must be frequently interrupted and altered by mountains and other causes.

M. de la Caille, who was sent thither by the French king to make astronomical observations, informs us, that at the Cape of Good Hope the main winds are the south-east and north-west; that other winds seldom last longer than a few hours; and that the east and north-east winds blow very seldom. The south-east wind blows in most months of the year, but chiefly from October to April; the north-west prevails during the other six months, bringing along with it rain, and tempest., and hurricanes. Between the Cape of Good Hope and New Holland the winds are commonly westerly, and blow in the following order: north-west, south-west, west, north ‡.

In the Great South Sea, from latitude 30° to 40° south, the south-east trade-wind blows most frequently, especially when the sun approaches the tropic of Capricorn; the wind next to it in frequency is the north-west, and next to that is the south-west.

* Guthrie on the Climate of Russia, Edin. Trans. ii.

† Pontoppidan's Nat. Hist. of Norway, part i.

‡ Meteorological Tables at the end of Philip's and White's Voyages.

From south latitude 40° to 50° the prevailing wind is the north-west, and next the south-west. From 50° to 60° the most frequent wind is also the north-west, and next to it is the west*.

Thus it appears that the trade-winds sometimes extend farther into the south temperate zone than their usual limits, particularly during summer; that beyond their influence the winds are commonly westerly; and that they blow in the following order: north-west, south-west, west.

Such is the present state of the history of the direction of the winds. In the torrid zone they blow constantly from the north-east on the north side of the equator, and from the south-east on the south side of it. In the north temperate zone they blow most frequently from the south-west; in the south temperate zone from the north-west, changing, however, frequently to all points of the compass; and in the north temperate zone blowing, particularly during the spring, from the north-east.

As to the velocity of the wind, its variations are almost infinite, from the gentlest breeze to the hurricane which tears up trees and blows down houses. It has been remarked, that our most violent winds take place when neither the heat nor the cold is greatest; that violent winds generally extend over a great tract of country; and that they are accompanied by sudden and great falls in the mercury of the barometer. The wind is sometimes very violent at a distance from the earth, while it is quite calm at its surface. On one occasion Lunardi went at the rate of seventy miles an hour in his balloon, though it was quite calm at Edinburgh when he ascended, and continued so during his whole voyage. The following Table, drawn up by Mr. Smeaton, will give the reader a pretty precise idea of the velocity of the wind in different circumstances†.

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* Wale's Meteor. Tables. † Phil. Trans. 1759. p. 165.

Miles per Hour.	Feet per Second.	Perpendicular Force on one square Foot, in Avoirdupois Pounds and Parts.	
1	1·47	·005	Hardly perceptible
2	2·93	·020	Just perceptible
3	4·4	·044	
4	5·87	·079	Gently pleasant
5	7·33	·123	
10	14·67	·492	Pleasant, brisk
15	22·	1·107	
20	29·34	1·968	Very brisk
25	36·67	3·075	
30	44·01	4·429	High wind
35	51·34	6·027	
40	58·68	7·873	Very high wind
45	66·01	9·963	
50	73·35	12·300	Storm or tempest
60	88·02	17·715	Great storm
80	117·36	31·490	Hurricane
100	146·7	49·200	Hurricane that tears up trees and carries buildings before it.

Let us now consider the cause of these numerous currents in the atmosphere.

It cannot be doubted that the surface of the earth under the torrid zone is much more heated by the rays of the sun than under the frozen or temperate zones; because the rays fall upon it much more perpendicularly. This heat is communicated to the air near the surface of the torrid zone, which being thereby rarefied, ascends; and its place is supplied by colder air, which rushes in from the north and south.

Now the diurnal motion of the earth is greatest at the equator, and diminishes gradually as we approach the poles, where it ceases altogether. Every spot of the earth's surface at the equator moves at the rate of fifteen geographical miles in a minute; at the 40° of latitude, it moves at about eleven miles and a half in a minute; and at the 30°, at nearly thirteen miles. The atmosphere, by moving continually round along with the earth, has acquired the same degree of motion; so that those parts of it which are above the equator move faster than those which are at a distance. Were a portion of the atmosphere to be transported in an instant from latitude 30° to the equator, it would not immediately acquire the

velocity of the equator; the eminences of the earth therefore would strike against it, and it would assume the appearance of an east wind. This is the case in a smaller degree with the air that flows towards the equator, to supply the place of the rarefied air, which is continually ascending; and this, when combined with its real motion from the north and south, must cause it to assume the appearance of a north-easterly wind on this side the equator, and of a south-easterly beyond it *.

The motion westward occasioned by this difference in celerity alone would scarcely be perceptible; but it is much increased by another circumstance. Since the rarefaction of the air in the torrid zone is owing to the heat derived from the contiguous earth, and since this heat is owing to the perpendicular rays of the sun, those parts must be hottest where the sun is actually vertical, and consequently the air over them must be most rarefied; the contiguous parts of the atmosphere will therefore be drawn most forcibly to that particular spot. Now since the diurnal motion of the sun is from east to west, this hottest spot will be continually shifting westwards, and this will occasion a current of the atmosphere in that direction. That this cause really operates, appears from a circumstance already mentioned: when the sun approaches either of the tropics, the trade-wind on the same side of the equator assumes a more easterly direction, evidently from the cause here mentioned; while the opposite trade-wind, being deprived of this additional impulse, blows in a direction more perpendicular to the equator †.

The westerly direction of the trade-winds is still farther increased by another cause. Since the attraction of the sun and moon produces so remarkable an effect upon the ocean, we cannot but suppose that an effect equally great at least is produced upon the atmosphere. Indeed, as the atmosphere is nearer the moon than the sea is, the effect produced by attraction upon it ought to be greater. When we add to this the elasticity of the air, or that disposition which it has to dilate itself when freed from any of its pressure, we cannot but conclude that the tides in the atmosphere are considerable.

* This cause of the trade-winds was first assigned by Hadley in 1734. See Phil. Trans. Abridg. viii. 500.

† This cause was first assigned by Dr. Halley in his essay on the trade-winds; and is certainly by far the most powerful of all the agents.

Now since the apparent diurnal motion of the moon is from east to west, the tides must follow it in the same manner, and consequently produce a constant motion in the atmosphere from east to west*.

All these different causes probably combine in the production of the trade-winds; and from their being sometimes united, and sometimes distinct or opposite, arise all those little irregularities which take place in the direction and force of the trade-winds.

Since the great cause of these winds is the rarefaction of the atmosphere by the heat of the sun, its ascension, and the consequent rushing in of colder air from the north and south, the internal boundary of the trade-winds must be that parallel of the torrid zone which is hottest, because there the ascension of the rarefied air must take place. Now since the sun does not remain stationary, but is constantly shifting from one tropic to the other, we ought naturally to expect that this boundary would vary together with its exciting cause; that, therefore, when the sun is perpendicular to the tropic of Cancer, the north-east trade-winds would extend no farther south than north latitude 23·5°; that the south-east wind would extend as far north; and that when the sun is in the tropic of Capricorn, the very contrary would take place. We have seen, however, that though this boundary be subject to considerable changes from this very cause, it may, in general, be considered as fixed between the second and fifth degrees of north latitude.

Though the sun be perpendicular to each of the tropics during part of the year, he is for one-half of it at a considerable distance; so that the heat which they acquire while he is present is more than lost during his absence. But the sun is perpendicular to the equator twice in a year, and never farther distant from it than $23\frac{1}{2}°$: being therefore twice every year as much heated, and never so much cooled as the tropics, its mean heat must be greater, and the atmosphere in consequence generally most rarefied at that place. Why then, it will be asked, is not the equator the boundary of the two trade-winds? To speak more accurately than we have hitherto done, the internal limit of these winds must be that parallel where the mean heat of the earth is greatest. This would be the equator, were it not for a reason which shall now be explained.

* This cause was first assigned by D'Alembert, in his "Dissertation on the Cause of the Winds."

It has been shewn by astronomers, that the orbit of the earth is an ellipsis, and the sun is placed in one of the foci. Were this orbit to be divided into two parts by a straight line perpendicular to the transverse axis, and passing through the centre of the sun, one of these parts would be less than the other; and the earth, during its passage through the smaller part of its orbit, would constantly be nearer the sun than while it moved through the other portion. The celerity of the earth's motion in any part of its orbit is always proportioned to its distance from the sun; the nearer it is to the sun, it moves the faster; the farther distant, the slower. The earth passes over the smaller portion of its orbit during our winter; which must therefore be shorter than our summer, both on account of this part of the orbit being smaller than the other, and on account of the increased celerity of the earth's motion. The difference, according to Cassini, is 7 days, 23 hours, and 53 minutes. While it is winter in the northern, it is summer in the southern hemisphere; wherefore the summer in the southern hemisphere must be just as much shorter than the winter as our winter is shorter than our summer. The summer in the northern hemisphere consists of 186 days, 11 hours, and 37 minutes, while in the southern it is only 178 days, 18 hours, and 11 minutes. They are to one another nearly in the proportion of 15 to 14·3; and the heat of the two hemispheres may probably have nearly the same proportion to one another. The internal limit of the trade-winds ought to be that parallel where the mean heat of the globe is greatest; this would be the equator, if both hemispheres were equally hot; but since the northern hemisphere is the hottest, that parallel ought to be situated somewhere in it; and since the difference between the heat of the two hemispheres is not great, the parallel ought not to be far distant from the equator.

The trade-wind would blow regularly round the whole globe if the torrid zone were all covered with water. If the Indian Ocean were not bounded by land on the north, it would blow there in the same manner as it does in the Atlantic and Pacific Oceans. Land is much more opaque than water; it becomes, therefore, much warmer when both are equally exposed to the influence of the sun. For this reason, when the sun approaches the tropic of Cancer, India, China, and the adjacent countries, become much hotter than the ocean which washes their southern coasts. The air over

them becomes rarefied and ascends, while colder air rushes in from the Indian Ocean to supply its place. As this current of air moves from the equator northward, it must for a reason already explained, assume the appearance of a south-west wind; and this tendency eastward is increased by the situation of the countries to which it flows. This is the cause of the south-west monsoon, which blows during summer in the northern parts of the Indian Ocean. Between Borneo and the coast of China its direction is almost due north, because the country to which the current is directed lies rather to the west of north; a circumstance which counteracts its greater velocity.

In winter, when the sun is on the south-side of the equator, these countries become cool, and the north-east trade-wind resumes its course, which had it not been for the interference of these countries, would have continued the whole year.

As the sun approaches the tropic of Capricorn, it becomes almost perpendicular to New Holland: that continent is heated in its turn, the air over it is rarefied, and colder air rushes in from the north and west to supply its place. This is the cause of the north-west monsoon, which blows from October to April from the 3d to the 10th degree of south latitude. Near Sumatra its direction is regulated by the coast: this is the case also between Africa and Madagascar.

The same cause which occasions the monsoons gives rise to the winds which blow on the west coasts of Africa and America. The air above the land is hotter and rarer, and consequently lighter, than the air above the sea; the sea air therefore flows in, and forces the lighter land atmosphere to ascend.

The same thing will account for the phenomena of the sea and land breezes. During the day, the cool air of the sea, loaded with vapours, flows in upon the land, and takes the place of the rarefied land air. As the sun declines, the rarefaction of the land air is diminished: thus an equilibrium is restored. As the sea is not so much heated during the day as the land, neither is it so much cooled during the night; because it is constantly exposing a new surface to the atmosphere. As the night approaches, therefore, the cooler and denser air of the hills (for where there are no hills there are no sea and land breezes) falls down upon the plains, and, pressing upon

the now comparatively lighter air of the sea, causes the land breeze.

The rarefied air which ascends between the second and fifth degrees of north latitude has been shown to be the principal cause of the trade-winds. As this air ascends, it must become gradually colder and consequently heavier; it would therefore descend again if it were not buoyed up by the constant ascent of new rarefied air. It must therefore spread itself to the north and south, and gradually mix in its passage with the lower air; and the greater part of it probably does not reach far beyond the 30°, which is the external limit of the trade-wind. Thus there is a constant circulation of the atmosphere in the torrid zone: it ascends near the equator, diffuses itself towards the north and south, descends gradually as it approaches the 30°, and returning again towards the equator, performs the same circuit.

If the attraction of the moon and the diurnal motion of the sun have any effect upon the atmosphere, and that they have some effect can hardly be disputed, there must be a real motion of the air westwards within the limits of the trade-winds. The consequence of this westerly current is an easterly current on its north and south side, as has been demonstrated by D'Alembert. Hence the frequency of south-west winds over the Atlantic Ocean and the western parts of Europe.

Mr. Kirwan has rendered it probable that the frequency of south-west winds in our latitudes, at least during winter, is owing to an opposite current, which blows in the eastern parts of our hemisphere, between the coast of Malabar and the Moluccas during the same season. This northern wind must be supplied from countries still farther north to the pole, which must be recruited in its turn from the countries to the south of it in the western parts of our hemisphere*.

Our theory of the variable winds is still too imperfect to attempt any thing like a satisfactory explanation of them. They evidently stamp the nature of every climate, and therefore depend upon causes which act with uniformity, notwithstanding all their apparent irregularity. They are all intimately connected with each

* Irish Trans. viii. 400.

other, and probably succeed each other in a certain order, though that order has not hitherto been observed. All that can be done at present is to offer a few unconnected remarks.

Winds appear usually to begin at that point towards which they blow *. They must therefore be owing to a rarefaction or displacing of the air in some particular quarter, either by the action of heat, or some other cause. This is more particularly the case when the wind blows with violence. Hurricanes are uniformly preceded by a great fall of the barometer: and the wind often flows in every direction towards the place where the barometer stands so low. One would be tempted in this case to suppose the sudden decomposition of a portion of the atmosphere. Strong north-east winds have been repeatedly observed beginning at the quarter towards which they flow. In 1740, Dr. Franklin was prevented from observing an eclipse of the moon at Philadelphia by a north-east storm, which came on about seven o'clock in the evening. He was surprised to find afterwards that it had not come on at Boston till near eleven o'clock: and upon comparing all the accounts which he received from the several colonies of the beginning of this and other storms of the same kind, he found it to be always an hour later the farther north-east for every 100 miles.

" From hence," says he, " I formed an idea of the course of the storm, which I will explain by a familiar instance. I suppose a long canal of water stopped at the end by a gate. The water is at rest till the gate is opened; then it begins to move out through the gate, and the water next the gate is first in motion, and moves on towards the gate; and so on successively, till the water at the head of the canal is in motion, which it is last of all. In this case all the water moves indeed towards the gate; but the successive times of beginning the motion are in the contrary way, viz. from the gate back to the head of the canal. Thus, to produce a north-east storm, I suppose, some great rarefaction of the air in or near the Gulf of Mexico; the air rising thence has its place supplied by the next more northern, cooler, and therefore denser and heavier air; a successive current is formed, to which our coast and inland mountains give a north-east direction †.

A similar storm was observed by Dr. Mitchell in 1802. It be-

* Kirwin, ibid. p. 397. † Franklin's Philosophical Lectures, p. 389.

gan at Charlestown on the 21st of February, at two o'clock in the afternoon; at Washington, which lies several hundred miles to the north-east, it was not observed till five o'clock; at New York it began at ten in the evening; and at Albany not till day-break of the 22d. Its motion, from this statement, was 1100 miles in 11 hours, or 100 miles in an hour *.

A remarkable storm of the same kind, and accompanied by an easterly wind, was observed in Scotland on the 8th of February 1799. It was attended by a very heavy fall of snow, and the motion of the wind was much slower. At Falkirk it began to snow at six in the evening of the 7th; at Edinburgh at about one o'clock in the morning of the 8th; and at Dunbar at eight o'clock in the morning. It lasted 11 hours, and did not travel above 100 miles during that time.

The north-east wind blows most frequently with us during the spring months; and from the observations made by Captain Cook, it appears that the same wind prevails during the same period in the Northern Pacific. Hence it appears that at that season the cold air from the north of Europe and America flows into the Atlantic and Pacific. Hence the reason of its uncommon coldness, dryness, and density.

It is very common to observe one current of air blowing at the surface of the earth, while a current flows in a contrary direction in the higher strata of the atmosphere. On one occasion I even observed three such winds blowing in contrary directions all at the same time. It is affirmed that changes of weather generally begin in the upper strata of the air; the wind which blows there gradually extending itself to the surface of the earth †.

Besides these more general winds, there are others which extend only over a very small part of the earth. These originate from many different causes. The atmosphere is composed of three different substances, air, vapour, and carbonic acid; to which may be added water. Great quantities of each of these ingredients are constantly changing their aërial form, and combining with various substances; or they are separating from other bodies, assuming the form of air, and mixing with the atmosphere. Partial voids,

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* Phil. Mag. xiii. 272.

† Derham and Gentil.—Kirwan, Irish Trans. viii. 404.

therefore, and partial accumulations, must be continually taking place in different parts of the atmosphere, which will occasion winds varying in direction, violence, and continuance, according to the suddenness and the quantity of air destroyed or produced. Besides these there are many other ingredients constantly mixing with the atmosphere, and many partial causes of condensation and rarefaction in particular places. To these, and other causes probably hitherto unknown, are to be ascribed all those winds which blow in any place beside the general ones already explained; and which, as they depend on causes hitherto at least reckoned contingent, will probably for ever prevent uniformity and regularity in the winds. All these causes, however, may, and probably will, be discovered; the circumstances in which they will take place, and the effects which they will produce, may be known; and whenever this is the case, the winds of any place may in some measure be reduced to calculation.

[*Thomson.*

SECTION II.

Methodical Arrangement, Intensity, and Velocity of Winds.

Those who would now wish to be perfectly understood, when treating of the winds, must previously make a new catalogue of them, including all such as have been lately discovered, and this addition made, they may then venture to enquire into their several causes and effects.

In this manner it is my intention to proceed; and to begin by making a new division of those, with which I am acquainted, into four different classes, or rather genera, of which, the first excepted, there are many different species.

The perennial; the periodical; the topical; and the general.

The perennial, as before observed, is the only wind which blows the same way throughout the year.

The periodical includes principally the monsoons, the Mediterranean etesian, or periodical winds, the tropical land wind, the khumseen, the scirocco, the long-shore wind, the harmattan, and the land and sea breezes.

The topical includes the sumyel, the mistral, and the Bengal north wester, which are all of them irregular, topical, and tempe-

rary, blowing always from the same point at particular places in sudden gusts, but of short duration.

The general winds are those which prevail in all parts of the world beyond the tropic, and might with equal propriety be called variable winds. These can only be discriminated from each other by the different degrees of velocity with which the current of air moves.

The tempest is both in cause and effect the same as a hurricane, or whirlwind: I shall therefore use these words synonymously, and place them in the first order, or degree of violent winds.

The storm, or what the English seamen call a hard gale, is likewise, I believe, nearly the same; I shall, therefore, make use of the former for the land, and the latter for the sea term, and reckon these in the second class: the French also sometimes speak of *des orages*, storms, as temporary gusts of wind, or squalls, which latter, however, in their own marine language are called "des grains de vent."

The gale has different gradations, as a hard gale or storm, approaching towards a tempest, a fresh gale, and a moderate gale; but the latter approaches towards a very fresh breeze. Then follows a moderate breeze, and finally a gentle breeze, which I consider as the slowest sensible motion of the air, not unappositely, though rather fantastically described, by a fine gentleman sailor in his journal, "gentle breezes languishing to a calm."

[*Capper.*

The force and intensity of different winds have been attempted to be calculated with great care and ingenuity by Mr. Rous. His Tables have been improved upon, and considerably augmented, by Dr. Young, upon a comparison with Mr. Lind's scale, and we thus copy them in their improved form.

Lind's gauge.	Force on a square foot in pounds av. by calculation.	Feet in 1″	Miles in 1 h.	Character.
	0.005	1.43	1	Hardly perceptible. R.
	0.020	2.93	2	Just perceptible, R.
	0.044	4.40	3	Gentle winds. R.
	0.079	5.87	4	
	0.123	7.33	5	
0.025	0.130			A gentle wind. L.
0.050	0.260			Pleasant wind. L.
	0.492	14.67	10	Pleasant brisk gale. R.
0.10	0.521			Fresh breeze. L.
	1.107	22.00	15	Brisk gale. R.
	1.968	29.34	20	Very brisk. R.
0.5	2.604			Brisk gale. L.
	3.075	36.67	25	Very brisk. R.
	4.429	44.01	30	High wind. R.
1.0	5.208			High wind. L.
	6.027	51.34	35	
	7.873	58.68	40	Very high. R.
	9.963	66.01	45	Great Storm. Derham.
2	10.416			Very high. L.
	12.300	73.35	50	Storm, or tempest. R.
3	15.625			Storm. L.
	17.715	88.02	60	Great storm. R.
4	20.833			Great storm. L.
	21.435	96.82	66	Great storm. La Condamine.
5	26.041			Very great storm. L.
	31.490	117.36	80	Hurricane. R.
6	31.250			Hurricane. L.
7	36.548			Great hurricane. L.
8	41.667			Very great hurricane. L.
9	46.875			Most violent hurricane. L.
	49.200	146.70	100	Hurricane that tears up trees and throws down buildings. R.
10	52.083			
11	57.293			
	58.450	160.00	109	Observed by Rochon.
12	62.5			

SECTION III.

Perennial or Trade-winds.

The west coast of Africa, from Cape de Verd to two or three degrees S. is said to be generally flat with a sandy soil. That part of it, therefore, which is situated near the equator, must be excessively hot at all seasons of the year, but particularly about the two equinoxes. Within many leagues of this coast, then, the sea for nearly ten months of the year, being much cooler than the land, the current of air to restore the equilibrium must necessarily come almost constantly from the westward, according to the situation of the sun and the bearings of the land. But it will very seldom vary

much from the western point near this coast, except at the two solstices. During the harmattan, and sometimes at other seasons, the wind will occasionally blow, a few hours before day, off the land, a circumstance perfectly well known to all commanders of ships in the Guinea trade, who are generally obliged to stand out from the coast, as near as they can to the westward of N. or S. according to their destination, to catch the perennial winds; and until they reach them, they are constantly baffled by squalls and calms accompanied with violent thunder and lightning, and frequently they meet with water-spouts.

On the opposite coast of America, for the same reason, the wind blows almost constantly towards the E. varying perhaps a few degrees N. or S. according to the nature and situation of the neighbouring coast, and also to the sun's place in the ecliptic; for on this coast there are likewise periodical winds, a sort of monsoons varying from the N. E. to the S. E.

In that part of Brazil which extends from the latitude of five degrees S. to the tropic, the wet season begins in April, when the wind changes to the S. E. with fresh gales accompanied with thunder and lightning. But in September, when the wind shifts to the N. E. it brings with it a clear sky and fair weather. There is no country on this continent within the tropics, where the heats are more tolerable, or the air more salubrious than in this part of America; for it is not only frequently refreshed with breezes from the sea, but being mountainous, it also abounds with lakes and rivers, which often overflow their banks, so that the climate of the inland country is equally temperate with the sea-coast.

But in the middle of this ocean, between the two great continents, and a very few degrees E. and W. of that central meridian, the regular perennial winds constantly prevail, subject to some slight variations according to the situation of the sun. Whilst he is near the equator, ships find great difficulty in passing the line, at which season they are sometimes becalmed until his declination increases to seven or eight degrees; but when it amounts to fifteen degrees N. or S. they generally cross it with a fresh breeze, and particularly when he is near either solstice. The perennial wind in both hemispheres varies likewise at these times; for when the sun is in Cancer, the S. E. perennial extends to four or five and even six degrees across the line to the northward, inclining more to the S. than the

E. On the contrary, when he is in Capricorn the N. E. perennial extends an equal number of degrees to the south of the equator, but it inclines more to the northward. All which facts clearly prove, that the lower current of air, being rarefied by the reflected heat of the sun, ascends, and the equilibrium is restored by a large body of dense air, which rushes forward in a right line, and with a strong current, to fill up the vacuum.

The early Portuguese and other European navigators, in attempting to sail towards the Cape of Good Hope, were greatly obstructed in their voyages thither by not adverting to these circumstances: but the use of the compass was then very little known. Most of them therefore endeavoured to keep close to the west coast of Africa, by which means, being then also ignorant of the real geography of this continent, they expected to shorten their distance; but thus situated, they necessarily encountered constant calms and tornadoes, and seldom performed their voyage out and home in less than two or three years: whilst some other adventurers, nearly about the same period, in trying to avoid these inconveniences, fell in with the American coast, and were likewise detained by the S. E. wind, which of course retarded their progress on that side, for they could not without great difficulty, and that only at particular seasons, make their way to the southward.

But the better-informed modern navigators, profiting by long and dear-bought experience, have learned to keep nearly the mid channel, where they are assisted by constant perennial winds, and where they may yet allow some room for leeway in the southern tropic, a precaution particularly necessary whilst the sun is near our summer solstice, for at that time the S. E. perennial wind inclines very much towards the southward. Both outward and homeward bound India ships pass the equator in the Atlantic in about 18 or 20 degrees W. By keeping this course they never fall in with the coast of America, either going to the Cape of Good Hope, or returning from it; and at the same time they avoid the calms on the coast of Africa.

After having passed the southern tropic three or four degrees, ships which sail from Europe between February and May seldom find themselves more than 26 or 28 degrees west; which by the trenching away of the American coast to the westward in these latitudes, is about half-way between the two continents. The winds

in these latitudes, in the month of May, are generally found variable, as if alternately and equally attracted by both continents; but as vessels advance to the southward in the months of May and June, and approach towards Africa, the wind between the latitude of 28 and 35 degrees S. comes round to the westward, and generally blows fresh from the N. W. until they have passed the Cape of Good Hope.

The wind just beyond the bounds of the perennial coming from this quarter, seems in some degree to confirm Dr. Halley's theory of the superior current of air in this situation forming a contrary current at the commencement of the temperate zone. This observation must be confined to particular seasons within certain limits, and not be considered as invariably the case, even in the southern Atlantic; for in those same parallels of latitude, the winds are light and variable, coming often from the S. E. and veering occasionally to almost every point of the compass. To the eastward of the Cape the S. E. wind blows frequently during their winter with considerable violence for several days successively. But the southerly winds to the eastward of the Cape blow with most violence when the sun is in Capricorn, that is during their summer months; for when the land on the extremity of the east coast of Africa is heated by the presence of the sun, the colder air from the antarctic circle, put in motion by the sun's melting the ice in those frozen regions, frequently rushes forward towards the land near the Cape of Good Hope with considerable force.

Bacon long since, and even Pliny before him, has in effect observed, that, from the vicinity of lofty mountains covered with snow, the winds blow periodically when the snow begins to melt. *Ubicunque siti sunt montes alti et nivales, ab ea parte flant venti stati ad tempus quo nives solvuntur.*

The S. E. perennial wind blows constantly some few degrees to the eastward of Madagascar at all seasons of the year, as far nearly as the island of Java, where it comes within the reach of the regular monsoon; and indeed between the island of Madagascar and the main land of Africa, commonly called the Mosambique Channel, the perennial winds are checked by the proximity of the two great bodies of land, and consequently partake of the nature of monsoons.

[*Capper on Winds and Monsoons.*

SECTION IV.

Periodical Winds.

Tropical Sea-winds or Monsoons.

THE name as well as the nature of the monsoons is misunderstood; the word is not derived from the name of a great mariner, but clearly from the Persian word mousum, meaning season. In tropical countries there are but two seasons: those in Hindostan are distinguished by the N. E. and S. W. monsoons. But farther to the eastward and southward of the line, and the gulf of Bengal, the monsoons blow from different quarters. The N. E. becomes in those parts the N. W. and the S. W. becomes the S. E. The causes of those changes and the original causes of the monsoons I shall hereafter attempt to explain, but first I shall endeavour to point out some generally prevailing errors respecting the course and changes of them in different parts of Hindostan, derived in all probability from the early navigators to India. As neither ancient nor modern geographers have yet fixed, with any degree of precision, the names or boundaries of the different oceans, seas, and gulfs where the monsoons prevail, to avoid further interruption and trouble I shall beg leave in this place to make a new division of them.

The gulf of Bengal is apparently so called on account of the rich and fertile province of that name, situated at the north, or head of it. In this gulf therefore no alteration is proposed. The S. W. boundaries of this gulf I shall fix at Dondre Head, on the island of Ceylon, latitude 5° 50′ N. and longitude 80° 48′ E. of Greenwich. And for the S. E. side, Acheen Head, latitude 5° 30′ N. longitude 95° 30′ E. For the northern extremity, the well known city of Calcutta, latitude 22° 34′ 45″ N. longitude 88° 29′ 30″ E. On the W. side of the Peninsula, the coast of Malabar, with Cape Guardafui, on the coast of Africa, forms another considerable gulf, frequently called the Arabian, but generally the Indian Sea: but this latter in particular seems to be a name equally applicable, and often applied to the gulf of Bengal, and even to the seas to the eastward and southward, and consequently is very indefinite; whilst the Arabian Sea may be confounded with the Red Sea or Arabian Gulf.

Adopting therefore in a great measure the plan of the oriental geographers, I shall name this sea the Gulf of Sind. The river Indus giving the name to the first, and Hindostan divided by the Ganges to the second division. The river Indus will then be placed at the head of one bay, and the Ganges at the head of the other; Tatta, a considerable city, situated on the former, and Calcutta on the latter. Tatta, according to Major Rennel, is in the latitude of 24° 50′ N. longitude, 67° 37′ E. Cape Guardafui to the S. W. latitude 12 degrees N. longitude 52° 30′ E. and Cape Comorin to the S. E. in the latitude of 7° 56′ N. longitude 78° 5′ E.

From the southern extremity of these two gulfs to the tropic of Capricorn, extending likewise eastward from the east coast of Africa to the west side of New Holland, I shall denominate the Indian Ocean, this being a considerable portion of the ocean leading to both gulfs in India, as well as to China and the eastern islands, including all India, both within and without the Ganges. From that parallel of latitude to the south pole, including that part of the ocean situated between the E. of Africa and the W. of New Holland, I shall call the Great Southern Ocean. These new divisions may not, perhaps, be deemed in every respect strictly accurate, but they will answer our purpose, and therefore, without further preface, we will now proceed to make some observations on the different monsoons and prevailing winds within these boundaries.

The winds in the gulf of Bengal are generally said to blow six months from the N. E. and the other six from the S.W. This is far from being precisely true respecting any part of India; it is, however, sufficiently accurate for our present purpose, and therefore I shall in part adopt this position as well as the common country name of monsoon; trusting, that in the course of this enquiry, I shall be able to account for the several deviations of the wind from the monsoon points, and at the same time in some measure to explain the causes of them.

From the island of Ceylon to Balasore Roads, the N. E. monsoon is said to begin, near the coast of Coromandel, early in October. But in fact between the two monsoons, the expiration of the one and the commencement of the other, the winds and currents are variable on this coast, partaking of both; frequently, however, calms prevail during the whole month of September; and even early

in October, with a strong current from the N. E. towards the S.W. At this period we must remember that the sun is fast approaching towards the equinox, which he crosses nearly about the 22d of September. As his declination afterwards increases from seven to fifteen degrees S. which is between the 10th and 31st of October, his absence from the northern hemisphere begins to be felt; and as he at the same time rarefies the air both by sea and land to the southward of the equator, the warm air then over the Indian Ocean, but particularly over the eastern side of the continent of Africa, as usual ascends, and the cold air from the N. meeting the perennial east wind, they pass forward progressively, beginning where the rarefaction takes place, and probably continuing to an immense distance, and thus form the N. E. monsoon. The exact point where the northerly wind terminates I shall not in this place attempt to ascertain; but we may venture to suppose, that it must be at least as far towards the N. E. as the West side of the Thibet and Napal mountains, separating India from China, and which in winter are always covered with snow. From this frozen eminence a current of cold air will move with considerable velocity towards the tropic, on the approach of the sun, until the equilibrium is restored; but at the latter end of January, the sun again beginning to return towards the N. produces a sensible effect on the air; for in proportion as he approaches towards the equator, the current of air in the gulf of Bengal, near the land, takes a different direction. About this time the wind, immediately on the coast of Coromandel, no longer blows violently or regularly from the N. E. as in the commencement of the monsoon, but first abates in strength (like a current of water when the level is nearly restored) and then changes daily to regular land and sea breezes, which of course, near the coast, are obviously occasioned by the alternate rarefaction of the air by sea and land.

In the Mosambique Channel the monsoons correspond nearly with those on the Malabar coast, if not in their commencement at least in their duration. The S. W. monsoon begins in April and continues till November. The N. E. then succeeds, and continues until April; but the S. W. monsoon in this channel is the fair season, and the wind varies sometimes towards the S. E. and E. S. E. on either coast, about the middle of November, where also there

are generally regular land and sea breezes. The N. E. monsoon regularly begins early in November near the Comero Islands and the north end of Madagascar, but seldom extends beyond St. Augustine's Bay to the southward, which is near the southern tropic. But on the east side of Madagascar, beyond the Islands of Bourbon and Mauritius, towards what are called the Eastern Islands, the S. E. perennial prevails all over the Indian Ocean, from the latitude of 11° to 28 degrees S. whilst to the south and eastward of the Islands of Java and Sumatra, the N. W. and S. E. monsoons alternately prevail at the different seasons of the year. The S. E. monsoon in these seas, according to Monsieur d'Apres, commences in the month of April and continues till November, when it changes to the N. W. but, between the two monsoons, the winds and currents there, as in other places, are light and variable. Throughout the whole extent of the Eastern Isles, as far as Timor and Solor, the N. W. monsoon brings bad weather; this wind is violent and accompanied with rain. The stormy weather continues all January and until the middle of February; it then abates, and entirely ceases about the end of March. In the month of April, the variable winds render the weather mild, and the sea is affected only by occasional squalls of short duration. In May, the S. E. wind becomes settled, and blows incessantly in June and July with considerable strength: during this time, however, the weather is fine, with a clear serene sky until the end of September. In the month of October, the S. E. monsoon dies away, and the winds become variable till they again settle in the N. W. As Dr. Halley mentions the difference of the monsoon in this part of the Indian Ocean south of the equator, but does not attempt to account for it, I shall in this place take upon me to offer some conjectures on the subject.

The earth, during the summer, as it has often been before observed, receives and retains a greater degree of heat from the sun than the sea, which, by its constant motion and change of surface, is at this season infinitely cooler than the land, particularly in the torrid zones; but during the winter, in the temperate zones, the sea is much warmer than the land, particularly in high latitudes. In the summer, therefore, the great body of air, near very extensive continents, will of course move from the sea to the land, and

in the winter quite the contrary will happen. Now if we refer to the map, we shall find New Holland an immense tract of land to the S. E. of the Sunda and Molucca Islands; and, if unbroken by a Mediterranean Sea, almost equal in extent to all the land in Europe. It is situated partly within and partly beyond the tropic. When, therefore, the sun is nearest his highest declination N. which of course is the winter of the southern hemisphere, and rarefies the air over the continent of Asia, the current of air in the southern hemisphere, independently even of the regular perennial wind, will move from the S. E. to restore the equilibrium to the N. W. on the contrary, in the months of November, December, and January, whilst the sun is nearly vertical over a part of New Holland, the current of air through the Sunda and Molucca Islands will come from the N. W. to fill up the vacuum made by the rarefaction, and thus occasion an alternate monsoon of S. E. and N. W.

This obvious manner of accounting for the N. W. and S. E. monsoons on the east side of the Indian Ocean, would not have escaped the discernment of the learned Dr. Halley, had he not become weary of the subject, or directed his attention towards pursuits of still greater importance. He closes his remarks concerning this subject with observing, "On this same principle, to the southward of the equator in part of the Indian Ocean, the N. W. winds succeed the S. E. when the sun draws near the tropic of Capricorn. But I must confess, that in this latter occurs a difficulty not easily to be accounted for, which is, why this change of the monsoons should be any more in this ocean than in the same latitudes in the Ethiopic Ocean, where there is nothing more certain than a S. E. wind all the year."

Having said every thing that appears to me necessary respecting the monsoons in the gulf of Bengal, the gulf of Sind, and the Indian Ocean, I shall offer a few words on the winds in the China Seas, and afterwards direct the reader's attention to the winds in the Arabian and Persian Gulfs.

In the gulf of Siam, on the coasts of Campogia or Campoge, of Cochin China, and in the gulf of Tonquin and China (according to Monsieur D'Apres de Mainvillette) the S. W. monsoon commences on the coast in the course of the month of April; but if out at sea in those parts, it does not change until a month later. It is for this

reason, that on the north part of Borneo to the islands of Paragoa and Luconia, it is seldom known to blow constantly but from the 1st to the 15th or 20th of May. As the S.W. monsoon continues only about six months, and commences near the coast, it there ceases first likewise in the same manner, and is immediately succeeded by the N. E. Thus, it is evident, the N. E. and S. W. monsoons reign constantly to the north of the line to the eastward, as well as in the gulfs of Bengal and Sind; whilst the N. W. and S. E. monsoons to the eastward, are absolutely confined to the south of the line, within the reach of the influence of New Holland. It has been already observed that the word monsoon, is derived from the Persian word *mousum*, season. The violent hurricanes in those seas are, by our sailors, called *tuffoon* or *typhon:* this term is derived either from the Greek τυφων, or from the Persian word *toofan*, a whirlwind or tempest. Whether the Greeks or Egyptians gave this word to the Persians, or received it from them, it is not necessary in this place to determine; but these and many other professional terms used by mariners in all parts of the east, both by the natives and Europeans, respecting the winds and weather, together with many of the ports of great resort on the different coasts in the Indian seas being called by a particular country name, with the addition of *bender*, signifying a port, and *banksala*, a magazine, render it extremely probable, and we may say almost certain, that the Persians were the earliest navigators of the Indian, and perhaps the China seas. The Portuguese succeeded them, and adopted the sea terms of their predecessors, which are now used by all other maritime nations, being however very much disguised by different European orthography and pronunciation.

In the Arabian and Persian gulfs, according to Mons. D'Apres, the winds are very different, although he remarks they are separated only by Arabia. " They blow," says this author, " in the Red Sea almost nine months in the year from the southward, that is from the end of August to the 15th of May, and sometimes to the end of that month, when the wind changes to the N. and N. N. W. and generally continues in that quarter to the end of August, but sometimes the land and sea breezes prevail."

In the gulf of Persia the N. W. wind blows from the month of October to July, and about three months from the opposite quarter. These winds, however, are not so regular as those in the Red Sea,

being often interrupted by fresh gales from the S.W. principally from Cape Moçandon, and sometimes by land breezes. *Id.*

2 *Etesian Wind.*

Throughout the whole Mediterranean, but mostly in the eastern branch, including the Adriatic and the Archipelago, the N.W. winds prevail in the summer months. During the winter they are variable, but the S.E. and S.W. blow frequently with great force near the two solstices.

In Greece, particularly in the Morea, which is almost surrounded by the sea, the Etesian winds, according to Aristotle, and other Grecian writers, blow about forty days, with their prodromi which precede them, as their name itself implies, about eight or ten days, making about fifty, both these together correspond nearly in their commencement and duration with the Khumseen wind in the Arabian Gulph. But the summer Etesiæ in Greece and the Morea come from the N.W. and the Khumseen from the S.W. These winds are likewise noticed by Pliny and Seneca, and also by Cicero, (Nat. Deor. ii. 53.) who says that in Italy they are equally comfortable and salutary to men, beasts, and birds, and likewise beneficial to vegetation, by moderating the violent heat of the weather during the inclement season of the dog-days.

When the sun advancing towards the N. has begun to rarify the atmosphere of the southern countries of Europe, the spring Etesiæ commence in the Mediterranean, which according to the ancients, blow in Italy during the months of March and April, and were called by the Roman writers the Favonii. Their influence at first will be but slightly felt, but as soon as the earth becomes considerably warmer than the Mediterranean, the current of air will then move from the sea towards the land, and consequently produce the Favonii or gentle western breezes, to which those authors allude.

For some weeks after the equinox, the warmth of the sun will not be very sensibly felt on the frozen Alps; but as his declination increases, some time even before the summer solstice, a part of the ice and snow on those mountains will begin to dissolve, and, according to the observation of Lord Bacon, put the air in motion from the northward, to fill up the vacuum produced by the rarefaction of the air over the southern part of Italy. This wind

therefore, at first will be light and variable, and give rise to the Prodromi, but will increase as the sun advances, so that this northerly current of air from the Alps, and westerly current of air from the Atlantic Ocean, continuing to move at right angles, and nearly with equal velocity from the same distance, will at length unite and produce a N. W. wind on the western part of Italy, which is the part whence the summer Etesiæ are said to blow.

In this manner it appears to me we may account for the periodical winds which are known to prevail both in Greece and Italy, and throughout every branch of the Mediterranean. But in the autumn all these winds become variable, sometimes blowing from the sea towards the coast, and at other times in a contrary direction. These frequent changes may probably be attributed to the sudden alteration in the temperature of the sea and land; for as the sun regularly declines towards the equinoctial, the earth, both on the continent of Europe to the northward, and of Africa to the southward, gradually cools again, subject for some time to slight variations, either on the earth or the sea, which must necessarily produce variable winds in the Mediterranean, until some weeks after the autumnal equinox. The western branch of the Mediterranean, situated between the Alpine regions to the N. and the continent of Africa to the S. must at all seasons be subject to violent changes of both wind and weather, particularly in the months of March and September, about the two equinoxes, when the sudden variations of heat and cold are greater than at any other time of the year. But as during the winter season the sea will generally be warmer than the land on either side, a current of air will move sometimes towards the Mediterranean from the continent of Europe, and nearly at the same time perhaps from that of Africa, which, late in autumn and throughout the winter, will produce opposite currents of air in every part of the sea, particularly near the respective coasts; and to these opposite currents of air may probably be imputed also the sudden storms, accompanied with heavy showers of rain, that frequently occur on the African side of the Mediterranean, during the early part of winter. The gusts of wind at this time, though violent, are generally of short duration. [*Id.*

It is to this periodical wind that Lucretius ascribes one, and

apparently the chief cause of the rise and exundation of the Nile. The passage occurs lib. vi. 712.

Nilus in æstatem crescit, campisque redundat,
Unicus in terris, Ægypti totius amnis:
Is rigat Ægyptum medium per sæpe calorem,
Aut, quia sunt æstate aquilones ostia contra,
Anni, tempore eo, qui *Etesiæ* esse feruntur;
Et, contra fluvium flantes, remorantur; et, undas
Cogentes surgus, replent, coguntque manere.
Nam, dubio procul, hæc adverso flabra feruntur
Flumine, quæ gelidis ab stellis axis aguntur:
Ille ex æstiferâ parte venit amnis, ab Austro
Inter nigra virûm percocto secla colore
Exoriens penitus mediâ ab regione diei.

The Nile now calls us, pride of Egypt's plains;
Sole stream on earth its bound'ries that o'erflows
Punctual, and scatters plenty. When the year
Now glows with perfect summer, leaps its tide
Broad o'er the champaign, for the north-wide now,
Th' Etesian breeze, against its mouth direct
Blows with perpetual winnow; every surge
Hence loiters slow, the total currents swells,
And wave o'er wave its loftiest bank surmounts.
For that the fix'd monsoon that now prevails,
Flows from the cold stars of the northern pole
None e'er can doubt; while rolls the Nile adverse
Full from the south, from realms of torrid heat,
Haunts of the Ethiop tribes; yet far beyond
Fish bubbling, distant, o'er the burning line.

Good.

3. *Tropical Land-wind.*

The island of Ceylon, which lies to the southward of the Coromandel coast, and where the peninsula becomes extremely narrow, partakes of both monsoons, but principally of the S. W. The wind immediately on the coast, at the commencement of this monsoon, takes nearly the same direction as the coast itself. From the latitude of 9 to 13 degrees, the coast lies nearly N. N. E. and S. S. W. and from the latitude of 15 degrees to the head of the gulf called Balascore Roads, it runs almost N. E. and S. W. The S. W. monsoon therefore on this coast blows at first along shore, from which cause it is called the Long Shore Wind. The nature of the soil on the coast probably contributes to give it this direc-

tion; for the soil being, in some respects, like the Gulf of Guinea on the coast of Africa, low and sandy, the air near the earth must consequently be much rarefied under almost a vertical sun, and the denser air, coming across the Indian Ocean or the Gulf of Sind, will follow that direction on the coast to fill up the vacuum. But these winds continue only to the end of May or the beginning of June, when the sun being near the summer solstice, the hot land wind on the coast of Coromandel commences, and continues about six weeks. To understand the causes of this sudden change, we must again advert to the geography of the country, and consider the state of the atmosphere at this period on the two coasts.

The southern part of the peninsula, from the latitude of 16 degrees to Cape Comorin, may be divided longitudinally into three parts, beginning at Madras, which is situated in the longitude of 80° 28′ 45″ E. About two degrees to the westward of that meridian is a range of mountains, forming the eastern boundary of the Valley of Baramaul, where the high land of Mysore commences, commonly called the Ballagat, or country above the Passes. This high or table land of Mysore rises at least 2,000 feet above the coast of Coromandel, and runs through the peninsula from N. to S. nearly in the longitude of $78\frac{1}{2}$ degrees. Two degrees farther to the westward is another range of mountains, which may be considered as the boundary of the Malabar coast; and the country situated between these two meridians, from 76 to 78 degrees, is properly the country of Mysore. With this sketch of the map of the country before us, and with a recollection of the first principle of this hypothesis, it will not be difficult to account for the hot land wind prevailing in the Carnatic during the months of May and June.

The sun's declination in the month of May is between 15 and 22 degrees N.; he will therefore before the end of this month have been vertical over all these countries, and consequently have produced a considerable degree of heat in the Carnatic; but at the same time the double range of mountains to the westward will have arrested the clouds brought thither by the S. W. monsoon, and made them precipitate their contents both on the Malabar coast and in the Mysore country. The principal point of rarefaction then, at this season, will be the Carnatic, which may, as usual, be considered as the heated room, and the nearest cold body of

air will come from the table land of Mysore to restore the equilibrium.

In the Carnatic, during the months of May and June, the thermometer of Farenheit in the shade is generally at 90 or even 100 degrees and upwards, whilst near the mountains the same kind of thermometer will not be more than 70 or 80 degrees at the utmost. The current of the air then will move from the mountains across the Carnatic towards the coast of Coromandel, and of course produce the hot land winds, but they are severely felt only on the east side of the Carnatic, at a distance from the mountains: at Amboor, and even at Vellore, which are situated near them, those winds are neither extremely hot, nor of long duration; and in the narrow part of the peninsula, in the beautiful little province of Coimbatore, although so far to the southward, in consequence of their vicinity to the hills, the inhabitants are never incommoded by land winds.

This rarefaction in the Carnatic, and the current of air which comes from the Ballagat Mountains, and blows from the W. to the E. to fill up the vacuum, are sufficiently strong inland to counteract the effects of the monsoon in this part of the peninsula; but the westerly wind soon loses its effect on coming to the coast, for it never extends above one or two leagues out to sea, where the S. W. monsoon blows incessantly at this season of the year.

But within a month after the summer solstice, the current of the S.W. monsoon begins to slacken, when the regular land and sea winds again commence upon the coast of Coromandel, and continue with slight variations for a month or six weeks. Towards the end of August, as the sun approaches the line, the heat in Asia and the cold in Africa begin to abate; consequently the monsoon daily becomes more faint, and like the slack water between the flood and ebb tides, the air in the Gulf of Bengal has little motion: frequently it moves about in eddies, and after it has fluctuated between the two monsoons for three weeks, sometimes almost a month, being attended with squalls from different quarters, the N. E. wind at length prevails, and like the change of tides, moves at first with considerable rapidity. But the tremendous gales, or rather hurricanes, which sometimes blow in the gulf at this season, and bear down every thing before them, seldom happen precisely at the beginning of the monsoon, nor does it appear that they are the

effect of a current of air like the monsoon, blowing constantly from the same quarter for several months, but rather resemble whirlwinds, which proceed principally from some sudden change in the upper regions of the atmosphere, and which, though extremely violent, are merely local and temporary. But before we conclude the account of the S. W. monsoon in Hindostan, it may be proper to observe, that this monsoon brings the violent rains into the provinces of Bengal and Bahar, which generally begin at Calcutta about the middle of June, two months after their commencement to the southward of the gulf. [*Capper.*

4. *Khumseen.*

The Arabian and Persian gulfs are not only separated by Arabia, but the major part of the former is within the tropic, whilst the northern part of it, like the whole of the gulf of Persia, from Muscat to Bossora, is situated beyond the tropic. In comparing the winds of these gulfs, therefore, we must make a distinction between the northern and southern division of the Arabian gulf. From the entrance of the Straights of Babelmandel to the city of Yambo, the S.W. monsoon prevails at the same time as it does in the Gulf of Sind, that is from April to September. But from the 15th of May to the beginning of August, the S.W. monsoon is extended, or rather elongated, from Yambo to Suez, notwithstanding the latter is almost eight degrees beyond the tropic. This wind is called by the Arabs the Khumseen (fifty), being supposed by them to precede the overflowing of the Nile about fifty days *.

The Khumseen wind blows in the northern part of the Arabian Gulf, as far as the sea-coast of the Delta.

It is very well known that the soil of Upper, and even of a part of Lower Egypt, on one side of the Arabian Gulf, and of Arabia Petrea and Arabia Deserta on the other, consists chiefly of rocks and sands. As the sun approaches towards the solstice, and from very obvious causes, for a month or six weeks afterwards, the atmosphere over those countries must be excessively rarefied; whilst this rarefaction continues to the northward, the air to the N. after the commencement of the rains, being infinitely more cold and dense, will be impelled forward towards the N. to restore the equi-

* The reader will hence observe that the Khumseen is synonymous with the prodromi, or breezes that precede and introduce the Etesian wind.—Editor.

librium, and consequently produce the Khumseen wind, which for the same reason will precede the overflowing of the Nile, and begin first near the principal point of rarefaction. But as the sun approaches again towards the autumnal equinox, the earth to the northward becomes cool, the Khumseen ceases to blow, the river begins to fall, and the N.W. wind again commences, and continues to blow all the rest of the year.

It is true, as was before mentioned, that almost the same winds prevailed at the same season in the Gulf of Persia as in the northern part of the Arabian Gulf; but the eastern shore of the former being covered with both hills and forests, the Khumseen will neither begin quite so soon in the Gulf of Persia as in Upper Egypt or Arabia, nor even continue to blow there with equal strength.

Id.

5. *Sirocco.*

This peculiar wind, sometimes written Scirocco and Sciloco, proceeds in the south part of Italy and Sicily from the S. E.; it blows occasionally with great force in the month of July, but sometimes commences faintly about the summer solstice.

This wind resembles the Khumseen, and the land wind in all tropical countries, not only in its appearance and effects, but likewise in the time of its commencement. It must be allowed, that it does not blow in the southern part of Europe without intermission for forty or fifty days, nor does it continue quite so long as those winds do in Asia and Africa, but it is extremely oppressive during the time it lasts, even to the Sicilians and Neapolitans.

According to Mr. Brydone, the inhabitants of Palermo do not understand in what manner to guard against its effects so well as the natives of Hindostan; for the Sicilians content themselves with merely shutting their windows, and where there are no shutters they hang up a wet blanket instead of them, which must be very soon dried; but the wiser Indian puts a curtain of grass before the window or door, which he constantly wets on the side exposed to the wind, and thus by keeping up a constant evaporation, the air which passes into the room is rendered perfectly cool.

Mr. Kirwan observes, that the degree of cold, produced by evaporation when the air is warmer than the evaporating surface,

is much greater than that which is produced when the evaporating surface is the warmer of the two. In this instance the air without is at 112 degrees even in the shade, and the evaporating surface, when frequently moistened, not more than 75 degrees. The most opulent and luxurious of the Hindoos make a sort of hut of perfumed grass, which is kept constantly moistened, and exposed to the land wind, in which they live at a temperature of 60 degrees during the extreme heat of the day, and the continuance of the land wind.

The Sirocco has been supposed by some people to come from the opposite coast of Africa, and by others to be the effect of sulphureous vapours from the earth; if, however, it came from the continent of Africa, it would be felt with great violence at sea, in the channel of Malta, and on the island itself; but the Sirocco is not felt at this time on any part of the sea which separates Sicily from Africa, but, like the land wind in India, it is confined to the shores on both sides, whilst the sea wind on the southern shores of Europe, opposite to Africa, is, at this season, always cool and refreshing.

Mr. Brydonne observes, that the Sirocco is felt with most violence at Palermo, situated on the N. W. side of Sicily, and on the continent it is infinitely worse in the interior of the country near Naples, than in the southern part of Calabria: these circumstances positively prove, that it is nothing more than the air, which acquires a considerable local degree of heat from the surface of the earth at the hottest season of the year, and in its ascent is impelled forward by the S. E. wind, so as to acquire additional heat as it proceeds towards the N. W. side of the island.

This progressive accumulation of heat from the land, during the Sirocco, may be ascertained by a person heating a piece of paper before the fire, and running the end of his finger along the heated paper; at first it will appear only warm, but as the finger proceeds, and accumulates the heat of that part of the paper over which the finger passes, it will at length become so hot as to be painful. [*Id.*

6. *Long-shore Wind.*

This is a kind of monsoon peculiar to the coast of the island of Ceylon, blowing from the south-west. We have hence already sufficiently described it under the article Monsoons. *Editor.*

7. *Land and Sea Breezes.*

When the earth begins to be violently heated in the course of the day, the rarefied air ascends, and the cooler air from the sea comes in to supply its place; but the exhalations raised during the day are condensed in the cool of the evening, during the absence of the sun, and falling down in copious dews, refresh the earth, when the sea becomes warmest, and the current of air, a few hours after sunset, goes from the land to the sea, and produces what is called the *land-wind*. It must be remembered, that these alternate land and sea breezes do not take place until some time after the change of each monsoon, when its strength begins to abate; for at the commencement of either, the monsoon itself blows incessantly for a month or five weeks immediately on the coast, and continues, with trifling deviations, from the N. E. or S. W. according to the respective seasons. Nor do the land or sea breezes at any time extend above three or four leagues from the shore.

Mr. Clare, in his "Treatise on the Motion of Fluids," shows the cause of these breezes by an easy and familiar experiment:—"Take," he says, "a large dish, fill it with cold water, and into the middle of this put a water-plate filled with warm water: the first will represent the ocean, the latter an island, rarefying the air above it. Blow out a wax-candle, and if the place be still, on applying it successively to every side of the dish, the fuliginous particles of the smoke, being visible and very light, will be seen to move towards the dish, and, rising over it, point out the course of the air from sea to land.

"Again, if the ambient water be warmed, and the dish filled with cold water, when the smoking wick of the candle be held over the centre of the plate, the contrary will happen, and show the course of the wind from land to sea."

During the continuance of the land and sea breezes on the coasts of Coromandel and Malabar, both in the N. E. and S. W. monsoons, the wind on shore seems regularly to follow the course of the sun, and passes very perceptibly round every point of the compass in twenty-four hours.

These winds blow constantly every year on the coast of Coromandel to the latter end of January, and continue during February

and to the beginning of March, subject to very slight variations; but as the sun approaches towards the vernal equinox, the winds again become variable for some days, as they were about the autumnal equinox, until his declination is upwards of 7° N. when the S. W. monsoon sets in, and often on the south part of the coast, with considerable violence. This change or reflux of air appears to be put in motion by the same means as that which comes from the opposite quarter; for, as the sun's altitude increases daily in the northern hemisphere, the extensive body of land in the N. E. part of Asia must become much hotter than the ocean, and consequently a considerable degree of rarefaction will be produced over that part of the continent, whilst at the same season an immense body of cold air will come both from the Indian Ocean and the continent of Africa, in the southern hemisphere, to restore the equilibrium. The principal tracts of land of different temperatures on the two continents, bearing very nearly N. E. and S. W. of each other, will, therefore, become alternately the two opposite extreme points of rarefaction and condensation, and necessarily, according to this theory, be the immediate causes of the N. E. and S. W. monsoons. [*Capper.*

8. *Harmattan.*

Drawn up by Dr. Dobson, from Mr. Norris's Communications.

The harmattan is a periodical wind, which blows from the interior parts of Africa towards the Atlantic Ocean, and possesses such extraordinary properties, as to merit the attention of the naturalist, making a curious and important article in the history and theory of the winds.

On that part of the coast of Africa which lies between Cape Verd and Cape Lopez, an easterly wind prevails during December, January, and February, which by the Fantees, a nation on the Gold Coast, is called the *harmattan*. Cape Verd is in 15° N. latitude, and Cape Lopez in 1° S. latitude, and the coast between these two capes runs, in an oblique direction, nearly W. S. W. to E. S. E. forming a range of upwards of 2100 miles. At the Isles de Los, which are a little to the northward of Sierra Leone, and to the southward of Cape Verd, it blows from the E. S. E. on the Gold Coast from the N. E. and at Cape Lopez and the river

Gabon, from the N. N. E. This wind is by the French and Portuguese who frequent the Gold Coast, called the N. E. wind, the quarter from which it blows. The English, who sometimes borrow words and phrases from the Fantee language, which is less guttural and more harmonious than that of their neighbours, adopt the Fantee word harmattan. The harmattan comes on indiscriminately, at any hour of the day, at any time of the tide, or at any period of the moon, and continues sometimes only a day or two, sometimes five or six days, and it has been known to last fifteen or sixteen days. There are generally three or four returns of it every season. It blows with a moderate force, not quite so strong as the sea breeze, which every day sets in during the fair season from the W. W. S. W. and S. W.; but somewhat stronger than the land wind at night from the N. and N. N. W.

1. A fog or haze is one of the peculiarities which always accompanies the harmattan. The gloom occasioned by this fog is so great, as sometimes to make even near objects obscure. The English fort at Whydah stands about the midway between the French and Portuguese forts, and not quite a quarter of a mile from either, yet very often from it neither of the other forts can be discovered. The sun, concealed the greatest part of the day, appears only for a few hours about noon, and is then of a mild red, exciting no painful sensation on the eye. The particles which constitute the fog are deposited on the grass, the leaves of trees, and even on the skin of the negroes, so as to make them appear whitish. They do not flow far over the surface of the sea: at two or three miles distance from the shore the fog is not so thick as on the beach; and at four or five leagues distance it is entirely lost, though the harmattan itself is plainly felt for ten or twelve leagues, and blows fresh enough to alter the course of the current.

2. Extreme dryness makes another extraordinary property of this wind. No dew falls during the continuance of the harmattan; nor is there the least appearance of moisture in the atmosphere. Vegetables of every kind are very much injured; all tender plants, and most of the productions of the garden, are destroyed; the grass withers, and becomes dry like hay; vigorous ever-greens likewise feel its pernicious influence; the branches of the lemon, orange, and lime trees droop, the leaves become flaccid, wither,

and, if the harmattan continues to blow for ten or twelve days, are so parched as to be easily rubbed to dust between the fingers: the fruit of these trees, deprived of its nourishment, and stinted in its growth, only appears to ripen, for it becomes yellow and dry, without acquiring half the usual size. The natives take this opportunity, of the extreme dryness of the grass and young trees, to set fire to them, especially near their roads, not only to keep the roads open to travellers, but to destroy the shelter which long grass, and thickets of young trees, would afford to skulking parties of their enemies. A fire thus lighted flies with such rapidity as to endanger those who travel: in that situation a common method of escape is, on discovering a fire to windward, to set the grass on fire to leeward, and then follow your own fire. There are other extraordinary effects produced by the extreme dryness of the harmattan. The covers of books even closely shut up in a trunk, and lying among clothes, are bent as if they had been exposed to the fire. Household furniture is also much damaged: the pannels of doors and of wainscot split, and any veneered work flies to pieces. The joints of a well-laid floor of seasoned wood open sufficiently to lay one's finger in them; but become as close as before on the ceasing of the harmattan. The seams also in the sides and decks of ships are much injured, and the ships become very leaky, though the planks are two or three inches in thickness. Iron-bound casks require the hoops to be frequently driven tighter; and a cask of rum or brandy, with wooden hoops, can scarcely be preserved; for, unless a person attends to keep it moistened, the hoops fly off.

The parching effects of this wind are likewise evident on the external parts of the body. The eyes, nostrils, lips, and palate, are rendered dry and uneasy, and drink is often required, not so much to quench thirst, as to remove a painful aridity in the fauces. The lips and nose become sore, and even chapped; and though the air be cool, yet there is a troublesome sensation of prickling heat on the skin. If the harmattan continues four or five days, the scarf skin peels off, first from the hands and face, and afterwards from the other parts of the body, if it continues a day or two longer. Mr. Norris, who frequently visited the coast of Africa, observed, that when sweat was excited by exercise on those parts

which were covered by his clothes from the weather, it was peculiarly acrid, and tasted, on applying his tongue to his arm, something like spirit of bartshorn diluted with water.

As the state of salt of tartar placed in the open air, and the quantity evaporated from a given surface of water, are obvious proofs of the comparative moisture or dryness of the atmosphere, Mr. Norris put the harmattan to each of these tests; and particularly to moisten salt of tartar ad deliquium, and exposed it to the night air during the time that the harmattan was blowing. The following is the account of the result of these experiments. Salt of tartar will not only remain dry during the night as well as in the day, but when liquefied so as to run on a tile, and exposed to the harmattan, becomes perfectly dry in two or three hours; and, exposed in like manner to the night air, will be dry before morning.

It appears, from experiments made by Mr. Norris, that if the evaporation of the whole year be supposed to go on in the same proportion with what occurred during a short and very moderate return of the harmattan, the annual harmattan evaporation would be 133 inches; and if the calculation was made in proportion to the evaporation which occurs during a longer visit from the harmattan, and a more forcible breeze, the annual harmattan evaporation would be much more considerable. If the annual evaporation be in like manner calculated, in proportion to the evaporation which took place subsequent to and preceding the harmattan, the annual evaporation at Whydah, on the Gold Coast, would be 64 inches, and he had found the annual evaporation at Liverpool to be 36 inches. These three therefore are in the following proportion; harmattan 133 inches, Whydah 64 inches, and Liverpool 36 inches.

3. Salubrity forms a third peculiarity of the harmattan. Though this wind is so very prejudicial to vegetable life, and occasions such disagreeable parching effects on the human species, yet it is highly conducive to health. Those labouring under fluxes and intermitting fevers generally recover in an harmattan. Those weakened by fevers, and sinking under evacuations for the cure of them, particularly bleeding, which is often injudiciously repeated, have their lives saved, and vigour restored, in spite of the doctor. It stops the progress of epidemics: the small-pox, remittent fevers, &c. not only disappear, but those labouring under these diseases,

when an harmattan comes on, are almost certain of a speedy recovery. Infection appears not then to be easily communicated even by art. In the year 1770 there were on board the Unity, at Whydah, above 300 slaves; the small-pox broke out among them, and it was determined to inoculate; those who were inoculated before the harmattan came on, got very well through the disease. About 70 were inoculated a day or two after the harmattan set in; but not one of them had either sickness or eruption. It was imagined, that the infection was effectually dispersed, and the ship clear of the disorder; but in a very few weeks it began to appear among these 70. About 50 of them were inoculated the second time; the others had the disease in the natural way: an harmattan came on, and they all recovered, except one girl, who had an ugly ulcer on the inoculated part, and died some time afterwards of a locked-jaw. Mr. Norris dissents from Dr. Lind, who speaks of the harmattan as "fatal and malignant; that its noxious vapours are destructive to blacks as well as whites; and that the mortality which it occasions is in proportion to the density and duration of the fog." The baneful effects here pointed out proceed from the periodical rains which fall in March, April, &c. and which are ushered in by the tornados, or strong gusts of wind from the N. E. and E. N. E. accompanied with violent thunder and lightning, and very heavy showers. The earth, drenched by these showers and acted on with an intense solar heat, as soon as the storm is over, sends forth such noisome vapours as strike the nostrils with a most offensive stench, and occasions bilious vomitings, fluxes, and putrid fevers. Besides these vapours, which are annual, there appears to be a collection of still more pestiferous matter, confined for a longer time, and issuing from the earth after an interval of five, six, or seven years. There may indeed be instances in which the harmattan comes loaded with the effluvia of a putrid marsh; and if there are any such situations, the nature of the wind may be so changed as to become even noxious.

It appears that, except a few rivers and some lakes, the country about and beyond Whydah is covered for 400 miles back with verdure, open plains of grass, clumps of trees, and some woods of no considerable extent. The surface is sandy, and below that a rich reddish earth; it rises with a gentle ascent for 150 miles from the sea before there is the appearance of a hill, without affording

a stone of the size of a walnut. Beyond these hills there is no account of any great ranges of mountains. With respect to the origin of this wind, Mr. Norris says, "the harmattan, according to Dr. Lind, arises from the conflux of several rivers about Benin: but when I was on a visit to the king of Dahomey, 120 miles north, or inland from the fort at Whydah, I there felt the harmattan blowing from the N. E. stronger than I have at any other time, though Benin then bore from me S. E." On this head Mr. Norris makes the following conjecture: "The intersection of three lines, viz. an east line drawn from Cape Verd, a north-east one from the centre of the Gold Coast, and a north line from Cape Lopez, would point out a probable source of this extraordinary wind." Three lines, drawn according to the direction of Mr. Norris, towards the points of the compass from which the harmattan blows on Cape Verd, the Gold Coast, and Cape Lopez, converge to a part of Africa about the 15th degree of north latitude, and the 25th degree of east longitude, which is that part of Africa where, according to Ptolemy, the mountains of Caphas are situated. From these mountains, according to the same authority, the river Daradus arose, supposed by some to be now the river Senegal. It may be conjectured, that the disagreeable Levant wind of the Mediterranean proceeds from the same part of the continent of Africa; for it prevails during the same season of the year, and may derive its qualities from the surface over which it passes.

The Fantees have given the name of harmattan to one of the eight seasons into which they divide their year. Aherramantah, or the harmattan, extends from the 1st December to the middle of February, about ten weeks. Quakorah, a wind up the coast, from S. S. W. to S. S. E. from the middle of February to the first week in March, about three weeks. Pempina, or tornada season, part of March, all April, and the greatest part of May, about twelve weeks. Abrenama, or the old man's and woman's children, that is, the Pleiades, the rainy season, the latter end of May, all June, and to about the 20th July, eight weeks. Atukogan, or five stars, that is, Orion, high wind and squally, the rains very heavy, to the middle of August, three weeks. Worrobakorou, or one star, the ceasing of the rains, about three weeks. Mawurrah, the name of a certain star; close foggy weather, and no breeze, the first three weeks in September. Boutch, no land breeze in this season, the wind blows

fresh down the coast, about six weeks. Autiophi, or the croziers; tornados and southerly wind, with some rain, generally called the latter rains, about four weeks, to the beginning of December, when the Aherramantah season again commences.

[*Phil. Trans. Abr.* 1781.

SECTION V.

Topical or Toral winds.

1. *Samiel or Sumyel.*

The Sumyel, strictly speaking, should rather be considered as an Asiatic than an African wind; for although it is said to prevail to the eastward of Belud-ul-Gerid, and the Libyan Desert, it is felt with its greatest force on the great Desert of Arabia, and sometimes in countries bordering on the Gulf of Persia. On the derivation of the term authors are very much divided, but they all agree respecting its appearance and effects.

Mr. Volney seems to consider the Sumyel the same as the Khumseen, and he calls it the Shamyala, supposing the name to be derived from Sham, the country of Syria.

But I am rather disposed to adopt the derivation of Sir J. Chardin, *Yel*, Turkish, wind, and *Sum*, Arabic, poison, particularly as the Persians likewise call it Bâd Samoum, which is precisely the same signification, poisonous wind. Nor should this wind be confounded with the Khumseen and Sciroceo, which proceed from the same cause, and are exactly the same in appearance and duration as the land wind of India. The two latter blow for seven or eight weeks, at the latter end of May, all June, and part of July, in almost all inland countries situated within and near the northern tropic; but the natives of those countries in general do not esteem these hot winds particularly unwholesome, whereas the Sumyel blows only occasionally, and is a transient pestiferous current of air containing a deleterious gas, that in its passage always proves fatal both to man and beast. It is true, that the Sumyel in one respect resembles the Khumseen, for it generally appears during the hottest time of the year, but the gusts of it are merely local and instantaneous.

The air on the N. W. side of the Desert of Arabia, whence the Sumyel comes, assumes for some minutes before it is felt a dusky hue. It moves with considerable velocity, and is accompanied with a hissing noise. Those who are attacked by this wind are generally destroyed. Some persons however have escaped its dreadful effects, who, on perceiving its approach, have thrown themselves prostrate on the ground, and enveloped their heads in many folds of cloth, or those who have put their faces close to the ground in the dust until it has passed. Camels are said to be sensible of its approach, and take this method of their own accord to avoid its fatal effects. Sir J. Chardin observes likewise, that persons who are killed by it are not much changed in external appearance, but that their limbs are very easily separated from the body.

A further though not a better account of this wind has also been published in the Annual Register, Vol. IX. taken from the relation of Mr. Vanderhulse, who was long resident for the Dutch at Ormuz, and who came from thence to Bombay in the year 1763.

[*Capper.*

2. *Simoom.*

This seems to be little more than a variety of the Samiel; and the term itself may indeed be derived from the same root. It is described by Mr. Bruce as an excessively hot wind peculiar to the country of Abyssinia. He frequently felt its influence; once when he and his company were on their way to Rascid, when they became so enervated, and their stomachs so weak, with such violent head-achs, that they were incapable of pitching their tents; but each wrapping himself in his cloak, resigned himself immediately to sleep. On the 13th of October, when at Chendi, to use his own words, "the poisonous simoom blew as if it came from an oven; our eyes were dim, our lips cracked, our knees tottering, our throats perfectly dry, and no relief was found from drinking an immoderate quantity of water. The people advised me to dip a sponge in vinegar and water, holding it before my mouth and nose, and this greatly relieved me." Mr. Bruce does not say from what quarter the simoom blows. [Editor *from* Bruce.

3. *Mistral or Circius, and Autun.*

The wind known in Provence, under the name of Mistral or Circius, comes from the Alps to the N. W. It is supposed to contribute greatly to the salubrity of the air, by dispelling the vapours from the marshes and stagnant waters in the southern parts of Provence and Languedoc, where also, as Mr. de Saussure observes, it subjects the inhabitants to great inconvenience, and sometimes to considerable losses.

This excellent philosopher imputes it to three causes:

First, The situation of the Gulf of Lyons, which is terminated by a sort of tunnel formed by the Alps and the Pyrennees, and whose sides, therefore, are the principal scenes of its ravages. All the winds between the N. and the W. are united in this gulf, which by Aulus Gellius is called Circius. (Lib. II. cap. 22. See also Pliny, (Lib. II. 46.)

The second, is that this gulf, being to the S. is lower and warmer than the parts adjacent, and as the inferior current of air goes always from the cold to the warm point, the Gulf of Lyons must necessarily be the centre of violent winds, both from the E. and the W.

The third cause is nearly included in the two preceding.

In opposition to the Mistral, another singular wind blows from the east or south-east, which is called *autun*. It is first perceived near Narbonne, and at Castlenaudari is very violent: this wind, which is hot, produces head-achs, with loss of appetite, and seems to swell the whole body. In the eastern part of Languedoc is frequently felt a cold and very strong north wind, which follows the course of the Rhone, in the valley through which it runs, from north to south, and is called *bise*, or *black*. Sometimes, in direct opposition to the latter, blows a sea-wind, which is usually accompanied with a drizzling rain; but when dry, has the same morbid effects as the *autun* in Upper Languedoc; beside, in the heat of summer, from the coast of Leucate to the Rhone, sea-breezes constantly set in, at nine or ten o'clock in the morning, and, to the great refreshment of the air, last till about five in the evening. Lastly, it is also observable, that at the foot of the Pyrennees, near the village of Bland, in a narrow valley, wholly environed with mountains, except towards the north-west, and through

various channels two or three hundred paces wide, blows a very cold west, or north-west wind, which prevails chiefly in the summer, and then only at night. In clear warm weather this wind is much brisker than in a dense cold atmosphere. In summer it cools the whole valley, and in winter prevents hoar frost; and as it blows only in the night the inhabitants of the village of Bland can winnow their corn at no other time.

EDITOR *from De Saussure.*

SECTION VI.

Occasional Winds: as Hurricanes, Tempests, Tornados, and Whirlwinds.

1. *Hurricanes of the West Indies, and their Causes, in a Communication from Capt. Langford to Mr. Bonavert.*

IT has been the custom of our English and French inhabitants of the Caribee islands to send about the month of June, to the native Caribees of Dominico and St. Vincent, to know whether there would be any hurricanes that year; and about ten or twelve days before the hurricane came, they would constantly send them word; and it very rarely was erroneous, as I have observed in five hurricanes, in the years 1657, 1658, 1660, 1665, and 1667. From one of these Indians, I had the following prognostics:

1. All hurricanes come either on the day of the full, change, or quarters of the moon. 2. If it be to happen on the full moon, observe these signs, during the change: the skies will be turbulent, the sun redder than usual, a great calm, and the hills clear of clouds or fogs over them, which in the high lands are seldom so: likewise in hollows or concaves of the earth, or wells, there will be a great noise, as of a storm, and at night the stars will look very large with burs about them, and the north west sky very black and foul, the sea smelling stronger than at other times; and sometimes for an hour or two of that day the wind blows very hard westerly out of its usual course. On the full of the moon you have the same signs, with a great bur about the moon, and frequently about the sun. The same signs must be observed on the quarter days of the moon, in July, August, and September; the months when the hurricanes are most prevalent; the earliest I ever heard

of, was the 25th of July, and the latest the 8th of September; but the usual month is August.

The method of avoiding the danger is to keep the ship sailable, with good store of ballast, the ports well barred and caulked, the top-masts and tops down, the yards laced a-port, keeping the doors and windows of the ship fast, and she will lie as well as in other storms; thus the ship being in readiness, they may stay in the road till the storm begins, which is always first at north, so to the north-west, till it comes round to the south-east, and then its fury is over. So with the north wind they may run away to the south, to get themselves sea-room, for the drift of the south-west wind, where it blows very fiercely. By these means, I have, by God's blessing, preserved myself in two hurricanes at sea, and in three at shore, greatly to my advantage, as I lost not a sail, yard or mast, in two great hurricanes.

The causes of these hurricanes, according to experimental observations of my time, are these:

1. It is known to men of experience, that to the southward of the tropics there is constantly a trade-wind, or easterly wind, which goes from the north to the south-east all the year round; except where there are reversions of breezes, and inlets near the land; so that when this hurricane, or rather whirlwind, comes in opposition to the constant trade-wind, then it pours down with such violence as exceeds any storms of wind. In the hurricane at Nevis, I saw the high mountain that was covered with trees left in most places bare.

2. It is remarked by all men, that have been in those parts where the sun comes to the zenith, that at his approach towards it, there is always fair weather; but at his return southwards, it occasions, off the north parts of the equinoctial, generally much rain and storms, as tornadoes, and the like; which makes the wind in the tornado come on several points. But before it comes, it calms the constant easterly winds; and when they are past, the easterly wind gathers force again, and then the weather clears up fair.

3. The wind being generally between the tropics and the equator easterly, unless at such times as before-mentioned: meeting with the opposition of these hurricanes, which come in a contrary

course to that trade-wind, causes this violent whirlwind, on the sun's leaving the zenith of Barbadoes, and these adjacent islands; by which the easterly wind loses much of its strength; and then the west wind, which is kept back by the power of the sun, with the greater violence and force pours down on those parts where it gets vent. And it is usual in sailing from Barbadoes, or those islands to the north, for a westerly wind, when we begin to lose our easterly wind, to have it calm, as it is before hurricanes: and then the wind springing up, till it comes to be well settled, causes the weather to be various; but after the settled westerly wind comes fresh, they have been constantly without those shufflings from point to point.

Here it is to be observed, that all hurricanes begin from the north to the westward, and on those points that the easterly wind blows most violently, the hurricane blows most fierce against it; for from the N. N. E. to the E. S. E. the easterly blows freshest; so does the W. N. W. to the S. S. W. in the hurricane blow most violent; and when he comes back to the S. E. which is the common course of the trade-wind, then it ceases of its violence, and so breaks up. Thus I take the cause of hurricanes to be the sun's leaving the zenith of those parts towards the south: and secondly, the reverse or rebounding back of the wind, which is occasioned by the calming of the trade-wind.

But it will be objected, why should not this storm be all over those parts of the West Indies, as well as Barbadoes and the Leeward Islands? To which I answer, that it has in about 25 years of my experience, taken its course from the Bermudas to the Caribees; but seldom or never carries such a breadth as from the latitude of 16 to 32 degrees, which are the latitudes of the places; but it has been observed, that when hurricanes have been in Martinico, which is within two degrees of latitude, and two degrees longitude, according to the miles of that circle, yet no hurricane has been in Barbadoes, nor could I ever call any of the former storms at Barbadoes hurricanes, till that last year in 1675. Again it has been noted, that hurricanes have done the like to the northwards: for when the hurricane has been in Antigua and St. Christopher, those ships that were only in the latitude of twenty degrees, had no hurricane, but constant westerly winds, reasonably fair, and then there were no hurricanes in Bermudas; and

when the hurricanes were at Bermudas, the Leeward or Caribee Islands had no hurricane: nor had those islands the hurricane when Barbadoes had it.

It may be also objected, why the hurricane was never known to go farther to the westward than Porto Rico, which lies in or near the latitude of those islands of St. Christopher? To this I answer, that from Porto Rico, downwards, both that island and Hispaniola, as well as other adjacent islands, are of vast magnitude, and very high lands, that of themselves most commonly give reversal or westerly winds at night, through the year; for there, for the reasons aforesaid, the easterly wind, towards night, calms, and those lands afford a land-wind, which the other islands cannot do, by reason of the smallness of those Caribee Islands; but very near the shore, the trade-wind having its full power till this general whirlwind comes, for the reasons aforesaid. I do imagine likewise, to the southwards of Barbadoes, where the tornadoes come frequently, there are no hurricanes; nor was there at Barbadoes, when these tornadoes commonly came there, which made some small reversal, though it was but for two or three hours: yet the easterly wind, giving some way by the sun's declining from that zenith, prevents this furious reverse, where it has no vent till it is forced by the violence of the two winds.

[*Phil. Trans.* 1698.

2. *Hurricanes of the Indian Coast.*

Dr. Halley seems to consider the hurricanes which blow occasionally in the month of October in the Gulf of Bengal, as of a similar nature to those in the West Indies, in which probably he is right; but at the same time it is evident, that he has been misinformed, respecting the time they generally happen in the East. He observes that our seamen suppose them to be the breaking up of the monsoon. In this circumstance the mariners have misled the philosopher; for the hurricanes seldom happen near the change or breaking up of the monsoons, but generally many days after their commencement, and sometimes about the middle of them. Both the N. E. and S. W. monsoons blow at first in fresh gales, but neither of them increase to violent hurricanes. It is from very obvious causes already sufficiently explained, that the one dies gradually away before the other begins. But we will first

adduce unquestionable proofs of these facts, and then endeavour to ascertain the causes of them.

The first hurricane on the coast of Coromandel, mentioned by Mr. Orme, in his History of Hindostan, was that which destroyed Le Bourdonai's fleet, after he had taken Madras in the year 1746. He attacked this fort in September, which surrendered to him in less than a month, on condition that private property should be protected. But Dupluix, the governor of Pondicherry, disputed the right of the admiral to make such a capitulation, and insisted on his seizing all property, both public and private. The correspondence on this subject, in which the virtuous admiral strenuously defended the rights of individuals and his own honour, detained him at Madras with his squadron much longer than otherwise he intended to have stayed; and on the 2d of October came on a hurricane, which in a few hours destroyed almost the whole French fleet, and in which twenty other ships of different nations were driven on shore. One of the ships, says Mr. Orme, foundered in an instant, and only six of the crew were saved. But it must be remembered that four vessels laden with effects sent from Madras, with three others lately arrived at Pondicherry from Europe, were not affected by this hurricane; the violence of which, therefore, did not extend more than sixty or eighty miles to the southward.

On the 31st of October, 1753, Mr. Orme mentions also a violent hurricane on land, which was felt mostly near Wandiwash; but as the same author, who is in general equally minute and correct, takes no notice of any bad consequences happening from it at sea, we may reasonably suppose that it did no mischief either at Madras or Pondicherry, although its principal violence was felt nearly half-way between both, and not more than sixty miles in a direct line from either.

The next, which occurred during the N. E. monsoon, was on the 30th of December, 1760, during the siege of Pondicherry. On the evening of that day the weather was fair, the rains had ceased, and there were regular land and sea breezes; but a heavy swell rolled in on the shore from the S. E. The next morning the sky was of a dusky hue, accompanied with a closeness in the air, but without that wild irregularity which prognosticates a hurricane. Towards the evening, however, the wind freshened from the N. W. and at eight at night increased considerably. About midnight the wind

veered round to the N. E. fell calm with a thick haze, and in a few minutes after flew round to the S. E. whence it blew with great violence. Almost all the ships might have been saved, had they taken the advantage of the wind blowing off the land, but the roaring of the wind and sea prevented the captains from hearing the signals for standing out to sea, and many of the ships were wrecked. The Newcastle, Queenborough, and Protector, were driven on shore a few miles S. of Pondicherry, and the crews were saved. The Norfolk, Admiral Stevens, returned next day; and on the 7th came in the Salisbury from Trinco Trincomalay S. and the Tiger from Madras N.; so that in these opposite directions of E. N. and S. the violence of the storm had not been felt. It is observed by mariners in the East Indies, that these hurricanes usually happen once in five years; but for this opinion I can find no reason, either from what I have heard from others, or have myself observed.

The next in succession to that of 1760-61, was in 1763. On the 20th of October in that year, many days after the N. E. monsoon had apparently commenced, the wind began to slacken, and the clouds in the evening appeared uncommonly red, particularly on the day preceding the hurricane. On the morning of the 21st, a strong wind blew off the land, and in the course of a few hours flew all round the compass. At this time the Norfolk man of war, Admiral Cornish, with the America and Weymouth, and the Royal Charlotte country ship of four hundred tons, remained in Madras roads, with several other country vessels. The wind began to blow from the N. W. and continued from that quarter from three or four hours, of which time the men of war availed themselves to put to sea, but it then suddenly changed to the eastward, and prevented most of the country ships from following their example. After having blown with incessant violence for fourteen hours, and with almost equal strength from every point of the compass, it at length ceased, but literally left only wrecks behind. All the vessels at an anchor were lost, and almost every person on board perished; but the men of war and the Royal Charlotte returned into the roads on the 24th. The former had felt the gale very severely whilst near the coast, but without sustaining any material injury; the latter vessel likewise, from staying rather too long at anchor, had lost her fore and main-masts, and was otherwise much damaged.

The last of these hurricanes on the coast of Coromandel, which it seems necessary to mention, is that which happened on the 29th of October, 1768. Of this sufficient notice was given, but the officers of the Chatham Indiaman, then in the road, did not avail themselves of it; for on the preceding evening the sea was violently agitated, the sun set in a haze deeply tinged with red, with every other prognostic of a gale of wind. But unfortunately there had been a misunderstanding between the captain and officers, and the former being on shore, the latter, probably waiting for orders, remained at anchor, notwithstanding they might have put to sea with the N. W. wind, which, as usual at the commencement of these hurricanes, blew off the land. The governor and council, who foresaw the danger even time enough to have prevented the loss of the ship, ordered signal guns to be fired with shot, by way of directing the officers to weigh anchor and stand out to sea; but either they did not hear the guns, or were too punctilious in waiting for orders, and in consequence of this inflexibility were lost, for the ship was never seen or heard of after the close of the evening of the 29th. It is possible they were not able to distinguish the signal guns, for many of the inhabitants of the fort, during the violence of the hurricane, did not hear them, and the flashes of the guns might be mistaken by the officers of the ship for those of lightning. The vessels, lying at this time at a single anchor in the open road of Pondicherry, were not in the least disturbed by this hurricane; neither were the effects of it in the smallest degree felt at any of our settlements to the northward. Ships which put to sea in due time very soon get beyond their influence to the eastward, and it is very well known that they never extend far inland. All these circumstances properly considered clearly manifest the nature of these winds, or rather positively prove them to be whirlwinds, whose diameter cannot be more than 120 miles, and the vortex seems generally near Madras or Pulicat, where a branch of the Ballagat mountains extends towards the sea. Those which happen in the N. E. monsoon generally fall with the most violence within a few leagues of this place, and never, I believe, reach to the S. of Porto Novo.

But at the commencement of the S. W. monsoon, violent gales are sometimes felt on the east side of Ceylon and the southern extremity of the coast; these however should be considered rather as

the tail of that on the Malabar coast, which extends itself over Cape Comorin, near the southern extremity of the peninsula. In that quarter, however, such gales seldom occur, and are always of short duration.

One instance only is to be found in Mr. Orme's History of a violent hurricane to the southward. In this instance, which happened on the 13th of April, 1749, near Porto Novo, on the coast of Coromandel, two of the company's ships were stranded near Cuddalore; and the Namur, one of Admiral Boscawen's squadron, with the Apollo hospital-ship, foundered. This is the only instance known to me, in thirty-five years, of a hurricane on the Coromandel coast during the S. W. monsoon, and the effects of this were not felt beyond 11° N.

On the coast of Malabar, however, this monsoon frequently blows with considerable strength at the commencement; but it must be observed that it does not begin at the same time on all parts of the coast, nor does it proceed rapidly in its course towards the N. For although the change of the monsoon generally takes place at Anjengo, about the time the sun becomes vertical at that place, it never reaches Bombay before the middle or rather the end of May; the latitude of the former is about 80° 30′ N. and of the latter 19°. On the 12th of April the sun is vertical at Anjengo, and about the 15th of May at Bombay. If then the difference of latitude and declination be compared, it will be found that the sun and the monsoon move almost precisely together, at the rate of about 20 miles per day: a circumstance which, above all others, tends to prove that the sun's motion in the ecliptic is the primary, if not the sole cause of the motion of the air, or rather of the course of the wind, at least in this part of the world, I mean on the Malabar coast.

Monsieur d'Apres however remarks, that the N. E. monsoon, in the Mosambique Channel, begins at the north end of Madagascar, and amongst the Comero Islands, in the first week of November; and at St. Augustine's Bay to the southward, at the end of the same month. If the distance of those two places in like manner be divided by the number of days, it will be found to correspond nearly with the daily difference of the sun's declination; consequently this fact will further corroborate the truth of this hypothesis; for the correspondence between the motion of the monsoon and the

daily difference of the sun's declination is exactly the same, not only in India, but likewise in both the northern and southern hemispheres.

I have no authentic account of hurricanes on the Malabar coast; but I recollect to have heard of one which happened in the month of May, 1762, off Goa, and of a second near Anjengo, which took place, I believe, about the middle of April, 1779. One of the company's cruisers was at that time lying at an anchor in the road; it attempted, too late, to put to sea, but was never afterwards seen.

From these accounts it seems very clear, that hurricanes never happen at the breaking up of the monsoons, nor precisely at their commencement, but rather some time after the change, and that they are local and of short duration. But this description of them is not confined to the Malabar coast, nor to that of Coromandel, they rage with equal if not superior violence in the southern hemisphere, particularly about the latitude of 20 degrees S. near the French islands, where many ships have been in great danger of perishing from their effects, amongst the rest the Ilchester Indiaman, in the year 1757. But the most accurate and authentic account, which I have received of hurricanes in these latitudes, was that of the hurricane which the Britannia Indiaman encountered in the year 1770. On the 10th of March, about midnight, the wind suddenly burst upon the ship from the S.E. and blew with considerable force, but shifted all round the compass in the course of a few hours. Between five and six in the morning a sudden gust carried away their topmasts and gib-boom, when lying-to under a balanced mizen; and nearly about the same instant the jolly-boat, hanging over the side by the mizen chains, was suddenly whirled up into the mizen shrouds, whence it fell into the sea, and was dashed in pieces. The wind having blown nearly with equal strength from opposite quarters, prevented the sea from rising, so that at the end of ten hours, when it subsided, the sea bore but very little appearance of having been violently agitated.

The following day, the rigging being repaired, they proceeded a few leagues to the westward, and met a French vessel that had not felt the hurricane; they were likewise overtaken by another ship which had followed the same tract as the Britannia without suffering the least inconvenience from it. These circumstances prove

positively, that in an east and west direction, this hurricane had not extended above 30 leagues, and likewise that the ship was nearly in its centre.

Thus then it appears that these tempests or hurricanes are tornadoes, or local whirlwinds, and are felt with at least equal violence on the sea-coast, and at some little distance out at sea. But there is a material difference in the situation of the sun when they appear at different places. On the coast of Coromandel, for example, they seldom happen, particularly to the northward, except when the sun is in the opposite hemisphere. On the Malabar coast they rage with most violence during the monsoon, whilst the sun is almost vertical. Near the island of Mauritius they are felt in January, February, and March, which may be deemed their summer months. And in the West Indies, according to Mr. Edwards's History of Jamaica, the hurricane season begins in August and ends in October.

[*Capper.*

3. *Hurricane in Huntingdonshire, Sept.* 8, 1741.

By Mr. S. Fuller, of Trin. Col. Camb.

This was the most violent hurricane of wind in these parts, that ever was known in the memory of man. Cambridge was not in the midst of the hurricane, so that it has escaped very well. Mr. F. happened to be at Bluntsham in Huntingdonshire, about ten miles north-west of Cambridge. They were there in the midst of the hurricane. The morning, till half an hour after eleven, was still, with very hard showers of rain. At half after eleven it began to clear up in the south, with a brisk air, so that they expected a fine afternoon. The south-west cleared up too, and the sun shining warm drew them out into the garden. They had not been out above ten minutes, before the storm was seen coming from the south-west: it seemed not to be thirty yards high from the ground, bringing along with it a mist, rolling along with such incredible swiftness, that it ran about a mile and a half in half a minute. It began exactly at twelve o'clock, and lasted about thirteen minutes, eight minutes in full violence: it presently uncovered the house, and some of the tiles, falling down to windward, were blown in at the sashes, and against the wainscot on the other side of the room; the broken glass was blown all over the room; the chimneys all

escaped; but the statues on the top of the house, and the ballustrades from one end to the other, were all blown down. The stabling was all blown down, except two little stalls. All the barns in the parish, except those that were full of corn quite up to the top, were blown flat on the ground, to the number of about sixty. The dwelling houses escaped best; there were not above twelve blown down, out of near one hundred. If the storm had lasted five minutes longer, almost every house in the town must have been down; for they were all, in a manner, rocked quite off from their underpinnings. The people all left their houses, and carried their children out to the windward side, and laid them down on the ground, and laid themselves down by them; and by that means all escaped, except one poor miller, who went into his mill to secure it against the storm, which was blown over, and he was crushed to death between the stones and one of the large beams. All the mills in the country are blown down. Hay-stacks and corn-stacks are some quite blown away, some into the next corner of the field. The poor pigeons that were caught in it, were blown down to the ground, and dashed to pieces. Wherever it met with any boarded houses, it seemed to exert more than ordinary violence on them, and scattered their wrecks about a quarter of a mile to the north-east in a line: Mr. F. followed one of these wrecks; and about 150 yards from the building, he found a piece of a rafter, many feet long, and about six inches by four, stuck upright two feet deep in the ground; and at the distance of 400 paces from the same building, was an inch board, nine inches broad, fourteen feet long: these boards were carried up into the air; and some were carried over a pond about thirty yards; and a row of pales, as much as two men could lift, were carried two rods from their places, and set upright against an apple-tree. Pales, in general, were all blown down, some posts broke off short by the ground, others torn up by the stumps. The whole air was full of straw: gravel-stones, as large as the top of his little finger, were blown off the ground in at the windows; and the very grass was blown quite flat on the ground. After the storm was over, he went out into the town, and such a miserable sight he never saw: the havoc above described; the women and children crying, the farmers all dejected; some blessing God for the narrowness of their escape, others wondering how so much mischief could be done with one blast of wind, which hardly lasted

long enough for people to get out of their houses. Two people, that were out in it all the time, said, that they heard it coming about half a minute before they saw it; and that it made a noise resembling thunder, more continued, and continually increasing. A man came from St. Ives, who says, the spire of the steeple, one of the finest in England, was blown down, as was the spire of Hemmingford, the towns having received as much damage as Bluntsham. There was neither thunder nor lightning with it, as there was at Cambridge, where it lasted above half an hour, and consequently was not so violent. Some few booths in Sturbridge-fair were blown down. The course of the storm was from Huntingdon to St. Ives, Erith, between Wisbeach and Downham to Lynn, and so on to Suetsham. Very few trees escaped: the barns that stood the storm, had all their roofs more damaged to the leeward side than to the windward. The storm was succeeded by a profound calm, which lasted about an hour; after which the wind continued pretty high till ten o'clock at night.

[*Phil. Trans.* 1741.

4. *Tempest at Wigton in Cumberland.*

By Mr. T. Thomlinson.

On the 6th of October, 1756, at night, happened a most violent hurricane, such as has not been known in these parts in any one's memory. It lasted four hours at least, from about eleven till three. The damage it has done is very deplorable. The corn has suffered prodigiously. Stacks of hay and corn have been entirely swept away: houses unroofed, and in several places driven down by its fury: trees without number torn up by the roots; others snapt off by the middles, and their fragments scattered over the adjoining fields. Some were twisted almost round, or split down to the very ground; and, in short, left in such a shattered, mangled condition, as scarcely any description can give an adequate idea of. The change in the face of the country was very surprising in one single night: for, to complete the dismally desolate scene, the several tribes of vegetables (in all their verdure the day before), as if blasted with æthereal fire, hung down their drooping heads. Every herb, every plant, every flower, had its leaves withered, shrivelled up, and turned black. The leaves on the trees, especially on the

weather side, fared in the same manner. The evergreens alone seem to have escaped. The grass also, in a few days time, recovered itself in a great measure.

Mr. T. at first agreed with the generality of people in their opinion, that lightning had done all this mischief: but on recollecting that there had not been much seen any where, in many places none at all, but that the effect was general, as far as ever the wind had reached; he began to think that some other cause might probably be assigned. Accordingly, he examined the dew or rain, which had fallen on the grass, windows, &c. in hopes of being enabled, by its taste, to form some better judgment of the sulphureous or nitrous particles, or of whatever other quality they were, with which the air was so strongly impregnated that night, as to produce such strange effects. Nor was he deceived in his expectations: for on tasting it, he found it as brackish as any sea-water. The several vegetables also which he tasted were all salt, more or less, and continued so for five or six days after; the saline particles not being then washed off, from the corn and windows in particular; the latter of which, when the moisture on the outside was exhaled next day, sparkled and appeared exceedingly brilliant in the sun-shine. The saltness he conceived had done the principal damage; for common salt dissolved in water, he found on experiment on some fresh vegetables, when sprinkled two or three times, on them, has the very same effect, except that it does not turn them quite so black; but particles of a sulphureous or * other quality, may have been mixed with it. That this salt water had been brought from the sea †, every body will allow; but the manner how ‡, is not so easy to conceive §.

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* In an adjoining bleach-yard, a piece of cloth, which had been left out all night, was turned yellow; and was not without some difficulty washed out again. Some also, which was spread out the next day, contracted the same colour.—Orig.

† The wind was westerly, and consequently would sweep the Irish sea.—Orig.

‡ No rain, or however very little, during the hurricane.—Orig.

§ Our readers will find various instances of such descent of saline particles in the preceding chapter xxxix, section v, where they will also perceive that the present writer must be mistaken in ascribing any part of the mischief to the salt.—Editor.

5. *General Remarks on Tornados or Whirlwinds.*

It has long been supposed that these phænomena are immediately connected with atmospheric electricity, and produced by its irregular diffusion: and it must be obvious from the preceding articles in this section, that hurricanes, or wind-tempests, are precisely of the same nature as tornados or whirlwinds, only somewhat less defined and limited in their action.

The ancients supposed *, that there were great varieties of whirlwinds, of which Pliny and Seneca give different accounts.

The typhon τυφων, is defined by them, *vortex igne faetus,* a vortex produced by fire, which causes dreadful hurricanes of wind, and destroys all things that come within its reach.

The prester comes from πρηθω, *incendo inflammo.* It was said to break forth with strong flashes of lightning, and to be generally accompanied with an ecnephias.

The latter is from νεφος, *nubes,* and is described as a sudden and impetuous wind, bursting forth from a dark cloud with little rain.

The exhydria was a violent whirlwind, attended with a great quantity of rain, and in fact the principal difference between an exhydria and an ecnephias was in the quantity of rain or water, which they were supposed to contain.

These whirlwinds are evidently of the same family, all the features of them being exactly similar, with some slight variations of character.

When a sudden and violent change is produced by fire, either common or electrical, in a considerable body of the atmosphere, the air from all sides suddenly rushes forward, and consequently concentrating to a point, forms a vortex; and when the cohesion of the air is broken, it will also of course precipitate the water it contains, and produce an ecnephias or exhydria; or where there is but little moisture in the atmosphere, a typhon or prester. The two first are probably the ascending whirlwinds, the others those which descend.

Air ascending or descending, says Dr. Franklin, may form the same kind of eddies or whirlings, the parts of air requiring a circular motion, and receding from the middle of the circle by

* There is a little incorrectness in this explanation of whirlwinds, as the reader will perceive on turning to chapter xli. section i.

centrifugal force, and leaving there a vacancy. If descending, it will be greatest above and will lessen downwards. If ascending, it will be greatest below and will lessen upwards, like a speaking trumpet standing with the largest end on the ground.

When the air descends with violence in some places, it may rise with equal violence in others, and form both kinds of whirlwinds. The air in its whirling motion receding every way from the centre or axis of the trumpet, leaves there a vacuum, which cannot be filled through the sides, the whirling air as an arch preventing; it must then press in at the open ends. The greatest pressure inwards must be at the lower end, the greatest weight of the surrounding atmosphere being there; the air entering rises within, and carries up dust, leaves, and heavier bodies, that happen to be in its way, as the eddy or whirl passes over land.

If it passes over water, the weight of the surrounding atmosphere forces up the water into the vacuity, part of which by degrees joins with the whirling air, and adding weight, and receiving accelerated motion, recedes still further from the centre or axis of the trump as the pressure lessens, and at last, as the trump widens, is broken into small particles, and so united with air as to be supported by it, and become black clouds at the top of the trump.

Thus these eddies may be whirlwinds at land and water-spouts at sea. A body of water so raised may be suddenly let fall, when the motion, &c. has not strength to support it, or the whirling arch is broken so as to admit the air falling into the sea. It is harmless, unless ships unfortunately happen to be directly under it; but if in the progressive motion of the whirl it has moved from the sea over the land, and there suddenly breaks, violent and mischievous torrents are the consequence.

[*Capper.*

6. *Dreadful Whirlwind at Cambridge in New England.*

By Professor Winthrop.

The morning of July 10, 1761, at Cambridge, was fair and hot with a brisk gale at south-west. The afternoon was cloudy. About five it began to rain, and thundered once. At Leicester, forty miles westward, about five o'clock the sky looked strangely; clouds from the south-west and north-west seemed to rush to-

gether very swiftly, and immediately on their meeting commenced a circular motion; presently after which a terrible noise was heard. The whirlwind passed along from south-west to north-west. Its first effects were discernible on a hill, where several trees were thrown down at considerable distances from each other. In this manner it proceeded the distance of six miles with the most destructive violence, tearing up and scattering about the trees, stones, fences, and every thing else in its way, forming a continued lane of ruins, of a few rods wide.

It met with only one dwelling-house in its course, that of one David Lynde, on which it fell with the utmost fury, and in a moment effected its complete destruction.

The house was of wood, two stories high, and both the chimneys of stone. Near the house were a shop and small shed; and the barn stood on the opposite side of the road, about ten rods distant. As soon as they perceived the storm coming near the house some men within endeavoured to shut the south door; but before they could effect it they were surprized by the falling of stones around them, from the top of the chimney, which was in the middle of the house. All the people in the house were in that instant thrown into such a consternation, that they can give no account of what passed during this scene of confusion, which was indeed very short. Where the house stood nothing remained but the sills, and greater part of the lower floor, with part of the two stacks of chimneys, one about ten feet, and the other not quite so high; the stones which had composed the upper part lying all around them. Except these sills, there were only three pieces of timber, and those very large, left entire; one of which, about sixteen feet long, and ten inches by eight, was found on the opposite side of the road, nearly south, about twenty rods distant from the house. The rest of the timbers, from the greatest to the least, lay broken and twisted to pieces between N. N. E. and E. for seventy or eighty rods from the house; some on the ground, others sticking into it a foot and two feet deep in all directions. Part of one of the main posts, about ten feet long, with part of one of the plats of nearly the same length, and a brace which holds them together, were left sticking in the ground, nearly perpendicular, to a great depth, in a field southerly from the house, about eight rods distant. The boards and shingles of the house, three or four

thousand new boards which lay by it, were so entirely shattered, that scarcely a piece could be found above four or five inches wide, and vast numbers were not more than two fingers wide; some within the course of the wind and some without, at great distances on both sides of it. What has been said of the boards and shingles was likewise true of the wooden furniture of the house: the tables, chairs, desks, &c. shared the same fate; not a whole stick was to be found of any of them. Some of the beds that were found were hanging on high trees at a distance. Of the heavy utensils, pewter, kettles, and iron pots, scarcely any was found. Some nails that were in a cask in the east chamber were driven in great numbers into the trees on the eastern side of the house. The shop and shed before mentioned were torn in pieces, nothing of the shop remained but the sills and floor; and a horse standing under the shed was killed. Only one person was killed.

From the whole, it seems highly probable that the house was suddenly plucked off from the sills (to which the upright posts are not fastened,) and taken up into the air, not only above the heads of the persons who were on the lower floor, but to the height of those parts of the chimneys which were left standing, where, by the violent circular motion of the air, it was immediately hurled into ten thousand pieces, and scattered to great distances on all quarters, except that from which the wind proceeded. And it further appears that the violence of the wind in that place was over as soon as the house was taken up; otherwise no person could have been left on the floor.

[*Phil. Trans.* 1761.

7. *Whirlwind at Corne-Abbas in Dorsetshire.*

By Mr. J. Dorby.

On Saturday October 30, 1731, about a quarter before one in the morning, there happened at Corne-Abbas, at Dorsetshire, a very sudden and terrible wind whirl-puff, as Mr. D. calls it: some say it was a water-spout, and others a vapour or exhalation from the earth. It began on the south-west side of the town, passing directly to the north-east, crossing the middle of the town in breadth 200 yards. It stripped and uncovered tiled and thatched houses, rooted trees out of the ground, broke others in the midst

of at least a foot square, and carried the tops a considerable way. The sign of the new inn, a sign of five feet by four, was broken off six feet in the pole, and carried across a street of forty feet breadth, and over an opposite house. It took off and threw down the pinacles and battlements of one side of the tower; by the fall of which, the leads and timber of great part of the north aisle of the church were broken in. The houses of all the town were so shocked, as to raise the inhabitants. No hurt was done but only across the middle of the town in a line. Nor no life lost. No other part of the neighbourhood or country so much as felt or heard it. It is supposed by the most judicious, that it began and ended within the space of two minutes. It was so remarkably calm a quarter after twelve, that the exciseman walked through two streets, and turned a corner, with a naked lighted candle in his hand, unmolested and undisturbed by the air; and as soon as over, a perfect calm, but was soon followed by a surprising violent rain.

[*Phil. Trans.* 1739.

8. *Relation of two considerable Hurricanes in Northamptonshire**.

By Mr. John Templer.

October 30, 1669, between five and six o'clock in the afternoon, the wind being westerly, at Ashby, in Northamptonshire, there happened a formidable hurricane, scarce bearing sixty yards in its breadth, and spending itself in about seven minutes of time. Its first observed assault was on a milk-maid, taking her pail and hat from off her head, and carrying her pail many scores of yards from her, where it lay undiscovered some days. Next it stormed the yard of one Sprigg, in Westthorp, a name of one part of the town, where it blew a waggon body off the axle-trees, breaking the wheels and axle-trees in pieces, and blowing three of the wheels so shattered over a wall: this waggon stood somewhat cross to the passage of the wind. Another waggon of Mr. Salisbury's was driven with great speed on its wheels against the side of his

* Perhaps these ought rather to be called tornados or whirlwinds, than hurricanes: we have retained, however, the term employed in the original, and have chiefly copied them to shew how nearly the whirlwind and hurricane are united.—Editor.

house. A branch of an ash-tree, so large that two stout men could scarce lift it, was blown over Mr. Salisbury's house, without hurting it; and yet this branch was torn from a tree 100 yards distant from the house. A slate was carried near 200 yards, forced upon a window of the house of Samuel Templer, Esq. and very much bent an iron-bar in it. Not to take notice of its stripping of several houses; one thing is remarkable, which is, that at Mr. Maidwell's it forced open a door, breaking the latch; thence passing through the entry, and forcing open the dairy door, it overturned the milk vessels, and blew out three panes or lights in the window: next it mounted the chambers, and blew out nine lights more. It tore off a great part of the roof of the parsonage-house. It blew a gate-post, fixed two feet and a half in the ground, out of the earth, and carried it many yards into the fields.

The other instance was October 13, 1670, at Braybrook, likewise in Northamptonshire, about eleven o'clock; when the wind, in a storm, assaulted a pease-rick in the field, uncovering the thatch of it, without touching another only twenty yards off. Thence it proceeded also to the parsonage, by a narrow current, scarce eight yards in breadth, blowing up the end of a barley-rick, therewith some stakes in it of near five feet long; without touching a wheat-hovel, within six yards of the barley-rick. It beat down a jack-daw from the rick with that violence as forced the guts out of the body, and made it bleed plentifully at the mouth. Thence it went in a right line to the parsonage-house, and took off the cover of all the houses in its compass. From hence it passed over the town without any damage, the rest of the town being low in situation, and went on to a place called Forthill, where it uncovered so much of a malt-house as lay within its line and breadth.

Braybrook stands in a valley, environed by hills on three sides, at three quarters of a mile distance from it. There is also a hill called Clackhill, within a mile of it, and exactly in that point of the compass in which the wind then blew: no other hill in its way till the wind had passed over all the places it damaged. There have also been two earthquakes in this town within these ten years, with little or no wind.

[*Phil. Trans.* 1671.

9. *Fiery Whirlwind at Holkham, Norfolk.*

By the Right Honourable Thomas Lord Lovell, F. R. S.

Some of Lord Lovell's ploughmen, being at work, about the middle of August 1741, on a fair day, at ten o'clock in the morning, saw on a heath about a quarter of a mile from them, a wind like a whirlwind, come gradually towards them, in a straight line from east to west. It passed through the field where they were at plough, tore up the stubble and grass in the ploughed ground, for two miles in length, and thirty yards in breadth. When it came to some closes at the top of a rising ground, some men there saw it appear like a great flash or ball of fire. To some others it appeared as a fire, and some saw only a smoke, and heard such a noise as fire makes when a barn is burning, and the wind making a terrible noise, like that of a violent fire, or like carts over a stoney ground, which passed by a house, tearing up the stones in the road; it tore up a rank of pales, sprung several of the posts out of their places, and carried a pewter plate that stood on the outside of the window about forty yards from the house; also a large box-cover, about an inch and a half thick and four feet square and crossbarred, was carried away much farther, and torn all to pieces; and the gravel and stones flew about like feathers. It also broke down some fences, and frightened the cattle. And, what is very remarkable, every where else but in this place, the weather was clear and fine, and no sign of any storm or disturbance whatever. There was a strong smell of sulphur, both before and after the wind passed, and the noise was heard a great while after seeing the smoke. They said it moved so slowly forward, as to be near ten minntes in coming from the closes to the house.

[*Phil. Trans.* 1742.

10. *Whirlwinds of Sand.*

It not unfrequently happens that the same violence of wind, and exhibiting a similar eddy, takes place in the sandy deserts of Africa and Arabia, and has occasionally swallowed up in its tremendous vortex caravans and whole armies.

Mr. Bruce has given a spirited description of one or two of

Engraved by Romney from a Drawing by Craig

for the Gallery of Nature & Art

WHIRLWIND OF SAND, IN THE DESART OF ARABIA.

London Published by R. N. Rose, 45 Holborn Hill, May 1, 1820.

those, of which he was an eye witness. "At one o'clock," says he, "we alighted among some acacia trees at Waadi el Halboub, having gone twenty-one miles. We were here at once surprised and terrified by a sight, surely one of the most magnificent in the world. In that vast expanse of desert, from W. to N.W. of us, we saw a number of prodigious pillars of sand at different distances, at times moving with great celerity, at others stalking on with a majestic slowness; at intervals we thought they were coming in a very few minutes to overwhelm us; and small quantities of sand did actually more than once reach us. Again they would retreat so as to be almost out of sight, their tops reaching to the very clouds. There the tops often separated from the bodies, and these, once disjoined, dispersed in the air, and did not appear more. Sometimes they were broken in the middle, as if struck with large cannon-shot. About noon they began to advance with considerable swiftness upon us, the wind being very strong at north. Eleven of them ranged alongside of us about the distance of three miles. The greatest diameter of the largest appeared to me at that distance as if it would measure ten feet. They retired from us with a wind at S. E. leaving an impression upon my mind to which I can give no name, though surely one ingredient in it was fear, with a considerable deal of wonder and astonishment. It was in vain to think of flying: the swiftest horse, or fastest sailing ship, could be of no use to carry us out of this danger; and the full persuasion of this rivetted me as if to the spot where I stood.

"The same appearance of moving pillars of sand presented themselves to us this day in form and disposition like those we had seen at Waadi Halboub, only they seemed to be more in number and less in size. They came several times in a direction close upon us, that is, I believe, within less than two miles. They began immediately after sunrise like a thick wood, and almost darkened the sun. His rays shining through them for near an hour, gave them an appearance of pillars of fire. Our people now became desperate, the Greeks shrieked out and said it was the day of judgment; Ismael pronounced it to be hell; and the Turcorories, that the world was on fire *."

Dr. Darwin has given an animated and correct description of

* Bruce's Travels, vol. IV. p. 553-555.

this fearful phenomenon in the following verses of his Botanic Garden.

> "Now o'er their head the whizzing whirlwinds breathe,
> And the live desert pants, and heaves beneath;
> Tinged by the crimson sun, vast columns rise
> Of eddying sands, and war amid the skies,
> In red arcades the billowy plain surround,
> And stalking turrets dance upon the ground.
> —Long ranks in vain their shining blades extend,
> To Demon-Gods their knees unhallow'd bend,
> Wheel in wide circle, form in hollow square,
> And now they front, and now they fly the war,
> Pierce the deaf tempest with lamenting cries,
> Press their parch'd lips, and close their blood-shot eyes.
> —GNOMES! o'er the waste YOU led your myriad powers,
> Climb'd on the whirls, and aim'd the flinty showers!—
> Onward resistless rolls the infuriate surge,
> Clouds follow clouds, and mountains mountains urge,
> Wave over wave the driving desert swims,
> Bursts o'er their heads, inhumes their struggling limbs;
> Man mounts on man, on camels camels rush,
> Hosts march o'er hosts, and nations nations crush,—
> Wheeling in air the winged islands fall,
> And one great earthy Ocean covers all!—

EDITOR.

CHAP. XLI.

THE PRESTER, OR WATER-SPOUT.

SECTION I.

General Remarks.

MANY of the preceding meteors, or atmospherical phænomena, and especially those decribed under the name of hurricanes, tornadoes, and whirlwinds, are connected, as we have occasionally hinted at already, with the electric state of the atmosphere. We now advance to a meteor that is still more decidedly of this compound character, and which seems to be a combination of wind, aqueous vapour, and electric fluid.

The existence of this singular and most active phænomenon has been long known to the philosophical world: and by the Greeks, and after them by the Romans, was described under the name of Prester, which imports a fiery fluid of some kind or other. Gassendi, indeed, contended that the Prester of the ancients was a mere tornado or whirlwind, but this was before the nature, or even the existence, of electricity, as a definite power, had been accurately ascertained, however suspected formerly: and we have already observed*, that Mr. Capper, in the preceding chapter, has been betrayed by so learned a guide into the same error, and has regarded the Prester as a whirlwind or tornado of a peculiar species. To prove this error, nothing more is necessary than to quote the description of the Prester, as given by Lucretius, and to follow up the quotation, with the explanation of his learned translator: by which it will abundantly appear, that the Prester, like the spout of the present day, was regarded as both a sea and land meteor, or in other words as filled with water, and without water; the term being more properly applied to the former, and the latter being correctly regarded and called a *mimic*, or *imitative* Prester; in reality the fiery whirlwind or hurricane which we have already noticed in one or two of the articles of the last section of the preceding chapter, or a phænomenon most closely allied to it.

The passage we advert to is as follows: lib. vi. 422.

Quod super est, facul est ex hiis cognoscere rebus,
Πρηστηρας Graiei quos ab re nominitarunt,
In mare quâ missei veniant ratione superne.—&c. &c.

Hence, with much ease, the meteor may we trace
Term'd, from its essence, Prester by the Greeks,
That oft from heaven wide hovers o'er the deep.
Like a vast column, gradual from the skies,
Prone o'er the waves, descends it; the vext tide
Boiling amain beneath its mighty whirl,
And with destruction sure the stoutest ship
Threat'ning that dares the boist'rous scene approach.
Thus solve th' appearance; that the maniac wind,
In cloud tempestuous pent, when unempower'd

* See Section vi. 5.

To burst its bondage, oft the cloud itself
Stretches cylindric, like a spiral tube
From heaven forc'd gradual downwards to the deep;
As though some viewless hand, its frame transpierc'd,
With outspread palm had thrust it from above.
This, when, at length, the captiv'd tempest rends,
Forth flows it, fiery, o'er the main, and high
Boils from its base th' exaggerated tide.
For, as the cone descends, from every point
A dread tornado lashes it without,
In gyre perpetual, through its total fall:
Till, ocean gain'd, the congregated storm
Gives its full fury to th' uplifted waves,
Tortur'd, and torn, loud howling midst the fray.
Oft, too, the whirlwind from the clouds around
Fritters some fragments, and itself involves
Deep in a cloudy pellicle, and close
Mimics the prester, length'ning slow from heaven;
Till, earth attain'd, th' involving web abrupt
Bursts, and the whirlwind vomits and the storm.
Yet, as on earth the mountain's pointed tops
Break oft the texture, tubes like these, at land
Far rarer form than o'er the marble main.

GOOD.

The translator's note upon this passage, in exposition of his author, is as follows, and we give it as affording a clear explanation of the nature and properties of this most singular and powerful meteor:

"Having discussed the phænomenon of thunder and lightning, he now proceeds to consider those of the water-spout, and the hurricane: and it is truly curious to observe how minutely he concurs with the philosophy of the present day, in regarding them as meteors of a similar nature and origin. *Prester*, indeed, as our poet informs us, is a Greek word signifying a fiery or inflammatory intumescence; and such, he asserts, is the essence of which this meteor (the *water-spout)* consists: whence it is obvious, that the term *ventus*, or *wind*, applied to it immediately afterwards, is employed generically, to express an elastic gas or ether, for which

Lucretius found no definite expression in his own language, rather than the nature of wind properly so called. It is an igneous or fiery aura, not indeed in the open act of combustion, but composed of the finest and most minute particles of a peculiar species of elementary fire, which, in a more concentrated form, would necessarily become luminous and burning.

"Gassendi, indeed, contends, that the Epicurean prester is not an igneous meteor, but a mere vortex of elastic air. But there can be no doubt of his being mistaken; for Lucretius not only employs a term to which fire, in some modification or other, either elementary or combined, is necessarily attached, but refers us, in the opening of the discussion, by way of explanation, to the constituent particles of lightning, which, he expressly declares, consist of the very finest and most attenuate fiery atoms.

"Fiery, too, and of the common essence of lightning, is this meteor asserted to be, by the philosophy of the present day. For it is regarded as an electrical phænomenon, as, indeed, is almost every atmospherical meteor, as well as a great variety that are subterraneous. In describing the powers and operation of the thunder-cloud, in note on v. 256 above, I have noticed its wonderful faculty of attracting, with almost instantaneous speed, the lighter and adscititious clouds in its vicinity, as I have also its submission to the still more strongly attractive power of that part of the earth which lies immediately beneath it, in a state of negative electricity, evidenced by its dipping downwards either in ragged and multiform fragments, or, where the film of the cloud is tenser, in more regular and unbroken protuberances. Retaining then these simple facts in our recollection, it will not be difficult to account for the phænomenon of the prester, or water-spout, upon the principles of the electric theory.

"A thunder-cloud, or cloud filled with electric matter, is first noticed to appear at sea in a sky so serene as to be totally destitute of adscititious clouds, and in an atmosphere so dry, as to be possessed of very little and impalpable vapour. Such is the general appearance of the horizon on the commencement of the water-spout. In such a situation, a thunder-storm cannot be the result, for want of the confederate assistance of additional clouds and vapours: but, from the circumstances enumerated above, a very considerable portion of mutual attraction must take place between this isolated

cloud, and the portion of the sea immediately beneath it, more especially if the sea be at this time negatively electrified, or destitute of the electric power of which the cloud has a vast surplus. From this mutual attraction, the water directly under the cloud will become protuberant upwards, rising like a hill towards the cloud above, which in the phænomenon we are now describing, it always does, and the cloud above will become protuberant downwards, elongating itself towards the elevated portion of water beneath. If, in this action of straining, the texture of the cloud be very slight, it will burst into a thousand fragments, and the electric matter contained within it will be quietly dissipated, or attracted to the ocean; but if it be stronger and more viscous, it will continue to stretch without bursting; and, like every other elastic substance, the more it stretches, the narrower will be the projected tube. Such, to the mariner, is the actual appearance of the column of the water-spout, precisely resembling a speaking-trumpet, with its base or broader part uppermost. When the mouth of this projected tube touches the rising hillock of water, if the attraction of the negatively electrified ocean be superior, the electric aura, we may naturally suppose, will be drawn downwards, and the empty cloud be totally dissipated; but, as will generally occur in the case of a positive force applied to a negative, if the attraction of the electric cloud prove victorious, it will continue to suck up the rising hillock of water till it is altogether sated, and can hold no more. At this time the cloud must necessarily burst from its own weight and distention, and, in proportion to its size, and the deluge of water and electricity it discharges, will be the mischief produced. It is said, that it may occasionally be rent, at a distance, by making a violent noise, on board the ship, in which it is perceived, by files, saws, or other discordant instruments; and, certainly, whatever will tend to agitate the air, in any considerable degree, affords some prospect of breaking the cloudy film, and thus dispersing the meteor: but the more ordinary method of shooting at it from guns of a large calibre, gives a much stronger, and, indeed, almost certain chance of success: for no mechanical power can agitate the surrounding atmosphere by any means so forcibly as the report of a large cannon: and if it be loaded with ball, it will give a double prospect of discharging the contents of this tremendous spectacle."

Upon that part of the description which relates to the mimic prester, Mr. Good observes as follows: " Lucretius here alludes to meteors of a similar description, but not quite so tremendous in their effect: and is generally supposed to refer to the hurricane, or, as the Greeks termed it, εκνεφια; which is equally an electrical phænomenon, and may be regarded as a prester occurring on land, and consequently as an electric cloud filled with elastic air only, or other vapours received from the atmosphere, and not often with water. It is produced in the same manner as the sea-prester, has the same kind of elongated tube reaching towards the negatively electrified portion of the earth by which it is attracted, and is accompanied, previous to its bursting, by a similar tornado of external air. This elongated tube, as well as the substance of the cloud itself, in the time of Shakspeare, was supposed to have its film or fibres condensed and rendered firmer by the operation of the rays of the sun; but there is no necessity for such an idea;

——the dreadful spout
Which shipmen do the hurricano call,
Constring'd in mass by the almighty sun.
TROILUS AND CRESSIDA.

" We may account for the phenomenon in this manner: that the thirsty cloud, in consequence of a more elevated position than ordinary in the atmosphere, at the time it commences its attraction with the water below, satiates and distends itself, by means of its proboscis, with absorbed air alone, prior to the actual contact of such proboscis with the hillock of rising water; so that, by the time this elongating spout extends to the attracted hillock, it is totally incapable of containing any thing farther."

Cavallo thinks electricity rather a consequence than a cause of water-spouts; and notices that they sometimes vanish and reappear.

Franklin, in his work on electricity, conceives a vacuum is made by the rotatory motion of the ascending air, as when water is running through a tunnel, and that the water of the sea is thus raised. But it is justly observed by Dr. Young, that no such cause as this could do more than produce a slight rarefication of the air, much less raise the water to above thirty or forty feet. At the same time the

* Vol. iii. p. 106.

force of the wind thus excited might carry up much water in detached drops, as it is really observed to exist in water-spouts. Dr. Young remarks, moreover, in another passage, that the phænomena of water-spouts, if not of electrical origin, appear to have some connexion with electrical causes. A water-spout generally consists of large drops, like a dense rain, much agitated, and descending or ascending with a spiral motion, at the same time that the whole spout is carried along horizontally, accompanied in general by a sound like that of the dashing of waves. Spouts are sometimes, although rarely, observed on shore, but generally in the neighbourhood of water. They are commonly largest above; sometimes two cones project, the one from a cloud, the other from the sea below it, to meet each other, the junction being accompanied by a flash of lightning: and when the whole spout has exhibited a luminous appearance, it has perhaps served to conduct electricity slowly from the clouds to the earth. Some of these circumstances may be explained by considering the spout as a whirlwind, carrying up drops of water, which it has separated from the surface of the waves; and the remainder may perhaps be deduced from the co-operation of electricity, already existing in a neighbouring cloud.

[EDITOR.

SECTION II.

Genuine Presters or Water-Spouts.

1. *Observed in the Mediterranean.*

By Alexander Stuart.

AUGUST 27, 1701, being on the coast of Barbary, to the northward of the town of Bona, upwards of ten leagues distance at sea, about seven o'clock at night, soon after sunset, there appeared in the N.E. which was directly up the gulf of Lyons from us, great and continued flashes of lightning, one after another, with hardly any intermission, and this, without thunder, it continued till the next morning; the flashes of lightning sometimes representing the sudden appearance of a star, and at other times of a flaming sword, and again of a silver cord stretched along the clouds, or as the irregular rents of a phial from top to bottom. About eight next morn-

Engraved by Berry, from a Drawing by Craig

for the Gallery of Nature & Art

WATER SPOUT IN THE PACIFIC OCEAN.

London, Published by R. N. Rose 45 Holborn Hill, May 1. 1820.

ing we had thundering, with a continuation of lightning of the kind and appearance as before, all from the N. E. or nearly so.

About nine the same morning, there fell down from the clouds, which looked black, lowering, and as it were heavy with rain, in the N. E. three water-spouts; that in the middle, being the greatest, seemed as large as the mast of a ship, and I judged it to be at least a league and a half distant from us; so that in itself it was doubtless larger than three masts. The other two were not half the size. All of them were black, like the cloud from whence they fell; and smooth, without any knot or irregularity; only at first falling, some fell perpendicularly down, and some obliquely, and all of them smaller at the lower end than above, representing a sword; sometimes also one of them would bend, and become straight again, and also sometimes became smaller, and again increase its bulk; sometimes it would disappear, and immediately fall down again; at other times it became extenuated to the smallness of a rope, and again became gross as before.

There was always a great boiling and flying up of the sea, as in a jet d'eau, or water-work; or this rising of the water had the appearance of a chimney smoking in a calm day. Some yards above the surface of the sea, the water stood like a pillar, and then spread itself, and was dissipated like smoke: and the sword-like spout from the clouds either came down to the very middle of this pillar, as if it had been joined with it, as the largest pillar, which fell perpendicularly down, always did from the beginning to the end; or else it pointed to this column of water, at some distance, either in a perpendicular or oblique line, as did the two other lesser ones. There were three or four spouts more, which appeared at the same time in the same quarter of the heavens; but not like the three former, either for bulk or duration: these last appeared and disappeared several times, during the continuance of these three aforesaid.

It was hardly distinguishable whether the sword-like spout fell first down from the cloud, or the pillar of water rose first from the sea; both appearing opposite to each other all of a sudden: only I observed of one of them, that the water boiled up from the sea to a great height, without the last appearance of a spout pointing to it, either perpendicularly or obliquely; and here the water of the sea never came together in the form of a pillar, but rose up scat

teredly, the sea boiling furiously round the place. The wind being then N. E. the said boiling advanced towards the S. W. as a flitting or moving bush on the surface of the sea, and at last ceased. This shows that the boiling or flying up of the water of the sea may begin before the spout from the cloud appears: and indeed, if there be any small matter of priority between these two appearances, the boiling or throwing up of the sea-water has it; which first begins to boil, and then forms itself into a pillar of water, especially on the lower part.

It was observable of all of them, but chiefly of the large pillar, that towards the end it began to appear like a hollow canal, only black in the borders, but white in the middle; and though at first it was altogether black and opaque, yet one could very distinctly perceive the sea-water to fly up along the middle of this canal, as smoke does up a chimney, and that with great swiftness, and a very perceptible motion: and then soon after, the spout or canal burst in the middle, and disappeared by little and little; the boiling up and the pillar-like form of the sea-water continuing always the last, even for some considerable time after the spout disappeared, and perhaps till the spout appeared again, or reformed itself, which it commonly did in the same place as before, breaking and forming itself again several times in a quarter or half an hour.

I know not if any one has accounted for this phænomenon; but I imagine it may be solved by suction, or rather pulsion, as in the application of a cupping-glass to the flesh, after the air is first exhausted by the kindled flax.

It was further observable, that the oblique spouts pointed always from the wind; that is, that the wind being at N. E. the oblique spouts always pointed to the S.W.; though at the same time there were others perpendicular, which still continued so, notwithstanding the wind. Also that such as were curved, had always the convex side from the wind, and the concave towards it; that is, the wind being at N. E. the concave was towards the N. E, and the convex towards the S. W. It rained a great deal during the continuance of these spouts; and after their total disappearance, there was half an hour's violent storm from the N. E. with very little rain; but afterwards the weather cleared up.

Phil. Trans. 1702.

2. *Fall of Water from a Spout on the Moors in Lancashire.*

By Dr. Rich. Richardson.

This remarkable spout fell on Emott-moor, near Coln, in Lancashire, June 3, 1718, about ten in the morning. Several persons who were digging peat near the place where this accident happened, on a sudden were so terrified with an unusual noise in the air, that they left their work and ran home, which was about a mile from the place: but to their great surprise they were intercepted by water; for a small brook in the way was risen above six feet perpendicular in a few minutes time, and had overflown the bridge. There was no rain at that time on Emott-moor, only a mist, which is very frequent on those high mountains in summer. There was a great darkness in the place where the water fell, without either thunder or lightning. The meadows at Wicolae were so much flooded, that the like had not been seen in several years before, though it was there a very bright day.

I went to view the place where the water fell; though I believed this inundation might proceed from an eruption of water out of the side of the mountain; such being not unfrequent, where lead or coal have been dug, but neither have ever been sought for here. On approaching the place, I was struck with unspeakable horror: the ground was torn up to the very rock where the water fell, which was about seven feet deep, and a deep gulph made for above half a mile, and vast heaps of earth cast up on each side of it, some pieces remaining yet above twenty feet over, and six or seven feet thick. About ten acres of ground were destroyed by this flood. The first breach, where the water fell, is about sixty feet over, and no appearance of any eruption, the ground being firm about it, and no cavity appearing. The ground on each side the gulph was so shaken, that large chasms appeared at above thirty feet distance, which a few days after I observed the shepherds were filling up, lest their sheep should fall into them.

[*Phil. Trans.* 1719.

3. *Water-spout near the Lipari Islands.*

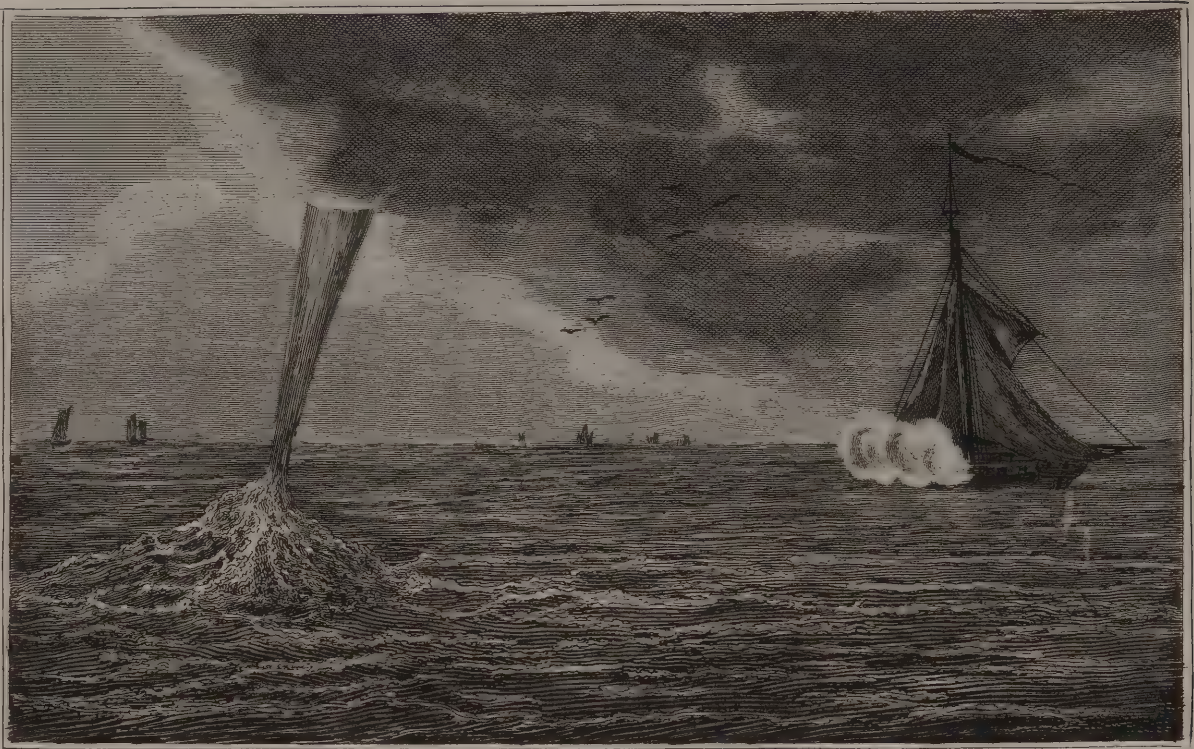
In a letter from William Ricketts, Esq. Captain in the Royal Navy, to the Right Hon. Sir Joseph Banks, Bart. &c. &c.

In the month of July, 1800, Captain Ricketts was suddenly called on deck, on account of the rapid approach of a water-spout among the Lipari Islands; it had the appearance of a viscid fluid, tapering in its descent, proceeding from the cloud to join the sea; it moved at the rate of about two miles an hour, with a loud sound of rain; it passed the stern of the ship, and wetted the after-part of the mainsail; hence Captain Ricketts concluded that water-spouts were not continuous columns of water; and subsequent observations confirmed the opinion.

In November, 1801, about twenty miles from Trieste, a water-spout was seen eight miles to the southward; round its lower extremity was a mist, about twelve feet high, nearly of the form of an Ionian capital, with very large volutes, the spout resting obliquely on its crown. At some distance from this spout, the sea began to be agitated, and a mist rose to the height of about four feet: then a projection descended from the black cloud which was impending, and met the ascending mist about twenty feet above the sea; the last ten yards of the distance were described with a very great rapidity. A cloud of a light colour appeared to ascend in this spout like quicksilver in a glass tube. The first spout then snapped at about one-third of its height, the inferior part subsiding gradually, and the superior curling upwards.

Several other projections from the cloud appeared, with corresponding agitations of the water below, but not always in spouts vertically under them: seven spouts in all were formed; two other projections were reabsorbed. Some of the spouts were not only oblique but curved: the ascending cloud moved most rapidly in those which were vertical; they lasted from three to five minutes, and their dissipation was attended by no fall of rain. For some days before, the weather had been very rainy with a south-easterly wind; but no rain had fallen on the day of observation.

[*Journal of the Royal Institution.*



Engraved by Clarke from a Drawing by Kongutseer

For the Gallery of Nature & Art

WATER SPOUT SEEN NEAR THE LIPARI ISLANDS.

London, Published by R. N. Rose, 45 Holborn Hill, May 1, 1820.

SECTION III.

Mimic, or False Presters, or Spouts with little or no Water.

1. *Spout observed at Hatfield, in Yorkshire.*

By the Rev. Abraham De la Pryme, F.R.S.

On the 15th of August, 1617, about two o'clock in the afternoon, there appeared a water-spout in the air, at Hatfield, in Yorkshire. It was about a mile off, coming directly to the place where I was; upon which I took my perspective glasses, and made the best observations on it I could.

The season was very dry, the weather extremely hot, the air very cloudy, and the wind pretty strong, and what was remarkable, blowing out of several quarters at the same time, and filling the air with thick and black clouds, in layers; this blowing of the wind soon created a great vortex, gyration, and whirling among the clouds, the centre of which now and then dropt down in the shape of a thick long black tube, commonly called a spout; in which I could distinctly see a motion, like that of a screw, continually drawing upwards, and screwing up as it were whatever it touched. In its progress it moved slowly over a hedge-row and grove of young trees, which it made bend like hazel-wands, in a circular motion; then advancing forward to a large barn, in a moment it plucked off all the thatch, and filled the whole air with it. Coming to a very large oak tree, it made it bend like the former, and broke off one of its strongest branches, and twisting it about, flung it to a very considerable distance off. Then coming near the place where I stood, within three hundred yards of me, I beheld with great satisfaction this extraordinary phænomenon, and found that it proceeded from a gyration of the clouds, by contrary winds meeting in a point or centre; and where the greatest condensation and gravitation was, falling down into a large pipe or tube, somewhat like the cochlea Archimedis; and which, in its working or whirling motion, either sucks up water, or destroys ships, &c. Having proceeded about a quarter of a mile farther, it was dissolved by the prevalency of the wind from the east.

[*Phil. Trans.* 1702.

2. *A second Spout observed at the same Place.*

By the same Writer.

The weather in this part of the country has been exceedingly wet and cool, so that it seemed to be spring rather than midsummer, yet June 21, 1702, was pretty warm, on the afternoon of which day, about two o'clock, no wind stirring below, though it was somewhat great in the air, the clouds began to be much agitated and driven together; on which they became very black, and were very visibly hurried round, from whence there proceeded a most audible whirling noise, like that commonly heard in a mill. After a while a long tube or spout came down from the centre of the congregated clouds, in which was a swift spiral motion like that of a screw, or the *cochlea Archimedis,* when it is in motion, by which spiral nature and swift turning, water ascends up into the one, as well as into the other. It proceeded slowly from west to north-east, broke down a great oak-tree or two, frightened the weeders out of the field, and made others lie down flat on their bellies, to avoid being whirled about and killed, as they saw had happened to several jackdaws, which were suddenly snatched up, carried out of sight, and then thrown a great way off among the corn; at length it passed over the town of Hatfield, to the great terror of the inhabitants, filling the whole air with the thatch it took off from some of the houses; then touching on a corner of the church, it tore up several sheets of lead, and rolled them together in a strange manner; soon after which, it dissolved and vanished, without doing any further mischief.

There was nothing more extraordinary in this, than in the other that I gave an account of in the preceding page; and by all the observations that I could make of both, I found that had they been at sea, and joined to its surface, they would have carried a vast quantity of water up into the clouds, and the tubes would then have become much more strong and opaque than they were, and have continued much longer.

It is commonly said that at sea, the water collects and bubbles up a foot or two high under these spouts, before they are joined: but this is a mistake, owing to the pellucidity and fineness of those tubes, which certainly touch the surface of the sea before any

considerable motion can be produced in it, and that when the pipe begins to fill with water, it then becomes opaque and visible. As for the reason of their dissolving of themselves, after they have drawn up a great quantity of water, I suppose it is by and through the great quantity of the water they have carried up, which must needs thicken the clouds, impede their motion, and by that means dissolve the tubes.

[*Id.* 1703.

3. *Spout raised off the Land in Deeping-Fen, Lincolnshire.*

By the Rev. Benjamin Ray.

May the 5th, 1752, a phænomenon appeared about seven in the evening, in Deeping-Fen, which, from its effects, seemed to be a water-spout, broken from the clouds. A watery substance, as it seemed, was seen moving on the surface of the earth and water, in Deeping-Fen. It passed along with such violence and rapidity, that it carried every thing before it: such as grass, straw, and stubble; and in going over the country bank, it raised the dust to a great height; and when it arrived in the wash, in the midst of the water, and just over against where Mr. R. lived, it stood still for some minutes. This watery substance spouted out water from its own surface, to a considerable height, and with a terrible noise.

On its second route, it proceeded in a side line into the river, breaking in its passage a fishing-net, and there moved along, till it came to the church, where it again stood a little while, and then made its next passage through the space between the church and the parsonage-house, towards Weston hills and Moulton chapel. In its way to these places, it tore up a field of turnips, broke a gate off its hinges, and another into pieces. Those who saw it evaporate, affirm it ascended into the clouds in a long spearing vapour, and at last ended in a fiery stream. There was a mist, like smoke, frequently round it. Three more were seen at the same time in different places.

[*Id.* 1751.

CHAP. XLII.

GENERAL NATURE AND PROPERTIES OF THE ELECTRIC FLUID.

SECTION I.

Its relation to common Matter.

It is not easy to give a more correct, concise, or perspicuous account of this subject than in the following epitome of Dr. Franklin's celebrated Treatise, by his friend William Watson, Esq.

Mr. Franklin's Treatise, says he, lately presented to the Royal Society, consists of four letters to his correspondent in England, and of another part intitled, 'Opinions and Conjectures concerning the Properties and Effects of the electrical Matter, arising from Experiments and Observations.'

The four letters, the last of which contains a new hypothesis for explaining the several phænomena of thunder-gusts, have either in the whole or in part been before communicated to the Royal Society. It remains therefore now only to lay before the Society an account of the latter part of this treatise, as well as that of a letter intended to be added to it by the author, but which arrived too late for publication with it.

This ingenious author, from a variety of well-adapted experiments, is of opinion, that the electrical matter consists of particles extremely subtile, since it can permeate common matter, even the densest metals, with such ease and freedom, as not to receive any perceptible resistance. Electrical matter, according to him, differs from common matter in this, that the parts of the latter mutually attract, and those of the former mutually repel each other; hence the divergency in a stream of electrical effluvia *: but that, though

* As the electric stream is observed to diverge very little, when the experiment is made in vacuo, this appearance is more owing to the resistance of the atmosphere, than to any natural tendency in the electricity itself. W. W.—Orig.

the particles of electrical matter do repel each other, they are strongly attracted by all other matter. From these three things, *viz.* the extreme subtilty of the electrical matter, the mutual repulsion of its parts, and the strong attraction between them and other matter, arises this effect, that when a quantity of electrical matter is applied to a mass of common matter of any size or length within our observation (which has not already got its quantity) it is immediately and equally diffused through the whole. Thus common matter is a kind of sponge to the electrical fluid; and as a sponge would receive no water, if the parts of water were not smaller than the pores of the sponge; and even then but slowly, if there was not a mutual attraction between those parts and the parts of the sponge; and would still imbibe it faster, if the mutual attraction among the parts of the water did not impede, some force being required to separate them; and fastest if, instead of attraction, there were a mutual repulsion among those parts, which would act in conjunction with the attraction of the sponge: so is the case between the electrical and common matter. In common matter, indeed, there is generally as much of the electrical as it will contain within its substance: if more is added, it lies without upon the surface*, and forms what we call an electrical atmosphere; and then the body is said to be electrified.

It is supposed, that all kinds of common matter do not attract and retain the electrical with equal force, for reasons to be given hereafter; and that those called electrics per se, as glass, &c. attract and retain it the strongest, and contain the greatest quantity. We know that the electrical fluid is in common matter, because we can pump it out by the globe or tube; and that common matter has near as much as it can contain; because, when we add a little more to any portion of it, the additional quantity does not enter, but forms an electrical atmosphere; and we know that common matter has not generally more than it can contain; otherwise all loose portions of it would repel each other, as they constantly do when they have electric atmospheres.

The form of the electrical atmosphere is that of the body which it surrounds. This shape may be rendered visible in a still air, by

* The author of this account is of opinion, that what is here added, lies not only without upon the surface, but penetrates with the same degree of density the whole mass of common matter, upon which it is directed.—Orig.

raising a smoke from dry resin dropped into a hot tea-spoon under the electrized body, which will be attracted and spread itself equally on all sides, covering and concealing the body. And this form it takes, because it is attracted by all parts of the surface of the body, though it cannot enter the substance already replete. Without this attraction it would not remain round the body, but be dissipated in the air. The atmosphere of electrical particles surrounding an electrified sphere is not more disposed to leave it, or more easily drawn off from any one part of the sphere than from another, because it is equally attracted by every part. But that is not the case with bodies of any other figure. From a cube it is more easily drawn at the corners than at the plane sides, and so from the angles of a body of any other form, and still most easily from the angle that is most acute; and for this reason points have a property of drawing on, as well as throwing off the electrical fluid, at greater distances than blunt bodies can.

From various experiments recited in our author's treatise, the preceding observations are deduced. And the following are a few of the other most singular ones. The effects of lightning, and those of electricity, appear very similar. Lightning has often been known to strike people blind. A pigeon, struck dead to appearance by the electrical shock, recovering life, drooped several days, ate nothing, though crumbs were thrown to it, but declined and died. Mr. F. did not think of its being deprived of sight; but afterwards a pullet, struck dead in like manner, being recovered by repeatedly blowing into its lungs, when set down on the floor, ran headlong against the wall, and on examination appeared perfectly blind; hence he concluded that the pigeon also had been absolutely blinded by the shock. From this observation we should be extremely cautious, how in electrizing we draw the strokes, especially in making the experiment of Leyden, from the eyes, or even from the parts near them.

Some time since it was imagined, that deafness had been relieved by electrizing the patient, by drawing the snaps from the ears, and by making him undergo the electrical commotion in the same manner. If hereafter this remedy should be fantastically applied to the eyes in this manner to restore dimness of sight, it will be well if perfect blindness be not the consequence of this experiment.

By a very ingenious experiment our author endeavours to evince

the impossibility of success, in the experiments proposed by others of drawing forth the effluvia of non-electrics, cinnamon, for instance, and by mixing them with the electrical fluid, to convey them with that into a person electrified; and our author thinks, that, though the effluvia of cinnamon and the electrical fluid should mix within the globe, they would never come out together through the pores of the glass, and thus be conveyed to the prime conductor; for he thinks, that the electrical fluid itself cannot come through, and that the prime conductor is always supplied from the cushion, and this last from the floor. Besides, when the globe is filled with cinnamon, or other non-electrics, no electricity can be obtained from its outer surface, for the reasons before laid down. He has tried another way, which he thought more likely to obtain a mixture of the electrical and other effluvia together, if such a mixture had been possible. He placed a glass plate under his cushion, to cut off the communication between the cushion and the floor; he then brought a small chain from the cushion into a glass of oil of turpentine, and carried another chain from the oil of turpentine to the floor, taking care that the chain from the cushion to the glass touched no part of the frame of the machine. Another chain was fixed to the prime conductor, and held in the hand of a person to be electrified. The ends of the two chains in the glass were near an inch from each other, the oil of turpentine between. Now the globe being turned could draw no fire from the floor through the machine, the communication that way being cut off by the thick glass plate under the cushion: it must then draw it through the chains, whose ends were dipped in the oil of turpentine. And as the oil of turpentine, being in some degree an electric per se, would not conduct what came up from the floor, the electricity was obliged to jump from the end of one chain to the end of the other, which he could see in large sparks; and thus it had a fair opportunity of seizing of the finest particles of the oil in its passage, and carrying them off with it; but no such effect followed, nor could he perceive the least difference in the smell of the electrical effluvia thus collected, from what it had when collected otherwise; nor does it otherwise affect the body of the person electrified. He likewise put into a phial, instead of water, a strong purging liquid, and then charged the phial, and took repeated shocks from it; in which case every particle of the electrical fluid

must, before it went through his body, have first gone through the liquid, when the phial is charging, and returned through it when discharging; yet no other effect followed than if the phial had been charged with water. He had also smelt the electrical fire, when drawn through gold, silver, copper, lead, iron, wood, and tbe human body, and could perceive no difference; the odour being always the same, where the spark does not burn what it strikes; and therefore he imagines, that it does not take that smell from any quality of the bodies it passes through.

Mr. Franklin, in a letter to Mr. Collinson some time since, mentioned his intending to try the power of a very strong electrical shock on a turkey. He accordingly has been so obliging as to send an account of it, which is to the following purpose. He made first several experiments on fowls, and found, that two large thin glass jars gilt, holding each about six gallons, were sufficient, when fully charged, to kill common hens outright; but the turkeys, though thrown into violent convulsions, and then lying as dead for some minutes, would recover in less than a quarter of an hour. However, having added three other such to the former two, though not fully charged, he killed a turkey of about 10 lb. weight, and believes that they would have killed a much larger. He conceited, that the birds killed in this manner eat uncommonly tender.

In making these experiments, he found that a man could, without great detriment, bear a much greater shock than he imagined; for he inadvertently received the stroke of two of these jars through his arms and body, when they were very near fully charged. It seemed to him an universal blow throughout the body from head to foot, and was followed by a violent quick trembling in the trunk, which went gradually off in a few seconds. It was some minutes before he could recollect his thoughts, so as to know what was the matter; for he did not see the flash, though his eye was on the spot of the prime conductor, from whence it struck the back of his hand; nor did he hear the crack, though the bystanders said, it was a loud one; nor did he particularly feel the stroke on his hand, though he afterwards found that it had raised a swelling there the size of a swan-shot or pistol-bullet. His arms and the back of his neck felt somewhat numbed the remainder of the evening, and his breast was sore for a week after, as if it had been bruised. From this experiment may be seen the danger, even under the greatest caution, to

the operator, when making these experiments with large jars; for it is not to be doubted, but that several of these fully charged would as certainly, by increasing them, in proportion to the size, kill a man, as they did before the turkey.

[*Phil. Trans.* 1751.

SECTION II.

1. *Communication and velocily of Electricity.*

By W. Watson, Esq.

In a former paper Mr. W. took notice, that among the many surprising properties of electricity, none was more remarkable, than that the electrical power, accumulated in any non-electric matter contained in a glass phial, described on its explosion a circuit through any line of substances non-electrical in a considerable degree; if one end of it was in contact with the external surface of this phial, and the other end on the explosion touched either the electrified gun barrel, to which the phial in charging was usually connected, or the iron hook always fitted in it. This circuit, where the non-electric substances, which happen to be between the outside of the phial and its hook, conduct electricity equally well, is always described in the shortest route possible; but if they conduct differently, this circuit is always formed through the best conductor, how great soever its length is, rather than through one which conducts not so well, though of much less extent.

It has been found, that in proportion as bodies are susceptible of having electricity excited in them by friction, in that proportion they are less fit to conduct it to the other bodies; in consequence, of all the substances we are acquainted with, metals conduct best the eleetrical powers; for which reason the circuit before spoken of is formed through them the most readily. Water likewise is an excellent conductor; for the electrical power makes no difference between solids and fluids as such, but only as they are non-electric matter.

Mons. le Monnier the younger, at Paris, in an account transmitted to the Royal Society, takes notice of his feeling the stroke of the electrified phial along the water of two of the basins of the Thuilleries, the surface of one of which is about an acre, by means

of an iron chain which lay on the ground, and was stretched round half their circumference. On these considerations it was conjectured, as no circuit had as yet been found large enough so to dissipate the electrical power as not to make it perceptible, that if the non-electrical conductors were properly disposed, an observer might be made sensible of the electrical commotion quite across the river Thames, by the communication of no other medium than the water of that river. In any other part of natural philosophy, as we should draw conclusions only from the facts themselves, it was determined to make the experiment.

The making this experiment drew on many others, and as the gentlemen concerned flatter themselves that they were made with some degree of attention and accuracy, they thought it not improper to lay a detail of all the operations before the Royal Society. To try this experiment, it was absolutely necessary that a line of non-electric matter, equal in length to the breadth of the river, should be laid over it, so as not to touch the water in any part of its length; and the bridge of Westminster was thought the most proper for that purpose, where the water from shore to shore was somewhat more than four hundred yards.

Accordingly on July 14, 1747, several members of the Royal Society met to assist in making the experiment. A line of wire laid along the bridge, not only through its whole length, but likewise turning at the abutments, reached down the stone steps on each side of the river low enough for an observer to dip into the water an iron rod held in his hand. One of the company then stood on the steps of the Westminster shore, holding this wire in his left hand, and an iron rod touching the water in his right; on the steps facing the former on the Surry shore, another of the company took hold of the wire with his right hand, and grasped with his left a large phial almost filled with filings of iron, coated with sheet-lead, and highly electrified by a glass globe properly disposed in a neighbouring house. A third observer standing near the second dipped an iron rod held in his left hand into the water, and touching the iron hook of the charged phial with a finger of his right hand, the electricity snapped, and its commotion was felt by all the three observers, but much more by those on the Surry shore. The third observer here was no otherwise necessary, than that the river being full, the iron was not long enough to be fixed in the mud on

the shore, and therefore was in want of some support. The experiment was repeated several times, both then and afterwards, and electrical motion felt across the river. The length of this circuit, through which the electricity was propagated, was at least eight hundred yards, more than four hundred yards of which was formed by the stream of the river.

The observers on the Westminster shore not feeling the electrical commotion equally strong with those of Surry, was judged to proceed from other causes besides that of distance. For it must be considered, that the conducting wire was almost throughout its whole length laid on Portland stone standing in water. This stone being in a great degree non-electric, is of itself a conductor of electricity; and this stone standing in water, no more of the electricity was transmitted to the observers on the Westminster shore than that proportion, on which iron is more non-electric, and consequently a better conductor of electricity than stone. Whether the conducting wire on the bridge was broken or no, and, consequently, whether the observers on the Westminster shore felt the electrical commotion or no, not only the observers on the Surry shore, who with their wire formed part of the line, felt the shock in their arms; but those persons who only stood on the stone steps there, and touched the wire with their fingers, felt the electrical commotion in the arm of that hand which touched the wire. Hence, and from a person feeling the electrical commotion standing on the wet stone steps of the Westminster shore, though not forming part of the line, but only touching the wire with his fingers, it was concluded, that besides the large circuit before spoken of, there were formed several other subordinate circuits, between the same steps of the Surry shore, and the bridge, by means of the water; by which that part of the electrical power, felt by the observers on the Surry side of the river, and not by those on the Westminster side, was discharged.

Dr. Bevis having observed, that which was likewise tried here, that however well an electrified phial was charged, its iron hook would not fire the vapours of warm spirits of wine held in a spoon and applied to it, if the person who held the phial, and who held the spoon, did not take each other by the hand, or have some other non-electrical communication between them; it was therefore thought proper to try the effects of electricity on some warm

spirit of wine through the large circuit before-mentioned. Accordingly the observers being placed as before, both on the Westminster and Surry shores, no other alteration was made in the before-mentioned apparatus, than that the wire which connected the gun-barrel with the iron hook of the coated phial being laid aside, the coated phial itself was charged at the gun-barrel, and then brought in the hands of an observer near the warm spirits in the spoon, which was placed on the short iron rod before-mentioned, which was connected with the wire which went to the observers on the Surry shore. On presenting properly the iron hook of the charged phial to the warm spirit, it was instantly fired, and the electrical commotion felt by the observers on both sides of the river.

It was then thought proper to try the effects of the charged phial on the warm spirit, when the wire was divided which was laid over the bridge; on presenting the iron hook to the spirit, a sufficient snap was given to the spoon to fire the spirit, but nothing so smart as in the former experiment where the large circuit was completed.

It was then tried what effect would be on the spirit, if the charged phial was divested of its long wire which lay over the bridge, and was only held in the hand of an observer; while the spoon with warm spirit was placed in contact of the irod rod before-mentioned, to which the wire was connected, which went to the observers on the Surry shore; and the spirit was fired with much the same degree of smartness as in the last experiment.

In these and all the subsequent operations, wires were made use of to conduct the electricity preferable to chains, as by great numbers of experiments it had been fully proved, that whatever difference there was in the bulk of the conductor, viz. whether it were a small wire, or a thick iron bar, the electrical strokes communicated were equally strong; and it had been further observed, besides the difficulty of procuring chains of a requisite length for the present purposes, that the stroke at the gun-barrel, when the electricity was conducted by a chain, was cæteris paribus not so strong, as when that power was conducted by a wire. This was occasioned by the junctures of the links of the chain not being sufficiently close, which caused the electricity in its passage to snap and flash at the junctures, where there was the least separation; and these smaller snappings in the whole length of the chain lessened the great one of the gun-barrel.

Encouraged by the success of these trials, the gentlemen were desirous of continuing their inquiries, and of knowing whether the electrical commotions were perceptible at a still greater distance. The New River near Stoke Newington was thought most convenient for that purpose; as at the bottom of that town, the windings of the river are such, that from a place which he calls A to another B, the distance by land is about 800 feet, but the course of the river is near 2000 feet. From A to another place C, in a right line is 2800 feet, but the course of the water is near 8000 feet.

Accordingly, on Friday July 24, 1747, there met at Stoke Newington the president of the Royal Society and several other gentlemen: when every thing being disposed as before, and the wire extended from A to B and C, over the meadow, without touching the water. When every thing was thus disposed, and the signals given, the charged phial was exploded several times, and the electrical commotion every time smartly felt by the observers both at A and B. In the like trials with the places A and C, the commotions were perceptible from A to C; a distance not less than two thousand eight hundred feet by land, and near eight thousand by water.

To execute this, to the former wire, which was already conducted to B, another was added, which there crossed the river without touching the water; and reached almost to C, where the first of a line of gentlemen held as before the wire in one hand, and the last dipped the iron into the water. The wire from the machine to A was as before. Its effects were plainly though but faintly perceived each time by some of the observers, but never by them all. The electrical commotion was always felt by that observer, who held the extremity of the wire, but never by him who held the iron-rod in the water. It was in one experiment felt by the observer who held the wire, not felt by the next who held the hand of the former, and yet plainly perceived by the third who joined the second. Those who did not themselves feel the electrical commotion here, did as at B, see the involuntary motions of those who did. The observers at A felt the shocks in the same degree, whether the other observers were stationed at B or C.

This experiment further demonstrates the distance to which the electrical power may be conveyed: but the same difficulty occurs here as in the last; *viz.* whether the circuit was completed by the water of the river, or by the ground which was wet?

To resolve this doubt then, the gentlemen met again July 28, 1747: when the electrical commotion was first tried from A to B before-mentioned, the iron-wire in its whole length being supported, without any where touching the ground, by dry sticks placed at proper intervals, of about three feet in height. The observers both at A and B stood on originally-electrics, and, on the signal, dipped their iron-rods into the water. On discharging the phial, which was several times done, they were both very much shocked, much more so than when the conducting-wire lay on the ground, and the observers stood on it, as in the former experiments. The same experiment was tried with the observer at A, instead of the iron-rod, dipping a narrow slab of Portland stone into the water of about three feet and a half in length; when the shock was felt, but not so severe as through the iron-rod. This demonstrated, as was before suggested, why the electrical commotion was not felt stronger by the observers on the western shore of Westminster bridge, *viz.* that Portland stone standing in water will conduct electricity very considerably.

The gentlemen then tried what would be the effect, if the observer at B stood on a cake of wax holding the wire as before, and touched the ground of the meadow with his iron-rod at least a hundred and fifty feet from the water; and if the observer usually placed near the river at A, had his wire carried a hundred and fifty feet over the river as the former, stood on an originally-electric, and touched the ground with his iron-rod. On the explosion of the charged phial, which was several times done, both the observers were smartly struck. This demonstrated, that in these instances the moist ground of the meadows made part of the circuit. The observers were distant from each other about five hundred feet.

The observers then, stationed as in the last experiment, stood on the wax cakes as before, without touching the ground with the iron-rods, or any part of their bodies, and the charged phial was exploded four times. These were not at all felt by the observer next to B, and without the greatest attention would not have been perceived by him next to A; and then only in some of the trials, the feeling of the electricity was like that of a small pulse between the finger and thumb of that hand which held the wire. The loaded phial was again discharged four times more, without any

other alteration in the disposition of the apparatus than that the observer next to B stood on the ground; when the electrical commotion was perceived by the observer, though not so sharp as when the other observer at the same time stood on the ground. The observer next to A felt the tingling between his finger and thumb as before.

The gentlemen were desirous of trying the electrical commotion at a still greater distance than any of the former through the water, and where, at the same time by altering the disposition of the apparatus, it might be tried whether that power would be perceptible through the dry ground only at a considerable distance. Highbury Barn beyond Islington was thought a convenient place for this purpose, as it was situated on a hill nearly in a line, and almost equi-distant from two stations on the New River, somewhat more than a mile asunder by land, though following the course of that river their distance from each other was two miles. The hill between these stations was of a gravelly soil; which, from the late continuance of hot weather without rain, was dry, full of cracks, and consequently was as proper to determine whether the electricity would be conducted by dry ground to any great distance, as could be desired. Accordingly, on Wednesday August 5, 1747, they met at Highbury Barn. The electrifying machine being placed up one pair of the stairs in the house there, a wire from the coated phial was conducted on dry sticks as before to that station by the side of the New River, which was to the northward of the house. —The length of this wire was three furlongs and six chains, or 2376 feet. Another wire fastened to the iron-bar, with which, in making the explosion, the gun-barrel was touched, was conducted in like manner to the station on the New River to the southward of the house. The length of this wire was four furlongs five chains and two poles, or 3003 feet. The length of both wires, exclusive of their turnings round the sticks, was one mile one chain and two poles, or 5379 feet. For the more conveniently describing the experiments made here, we will call the station to the northward D, and the other E.

At this distance the gentlemen proposed to try, first, whether the electrical commotion was perceptible, if both the observers at D and E, supported by originally-electrics, touched the conducting wire with one hand, and the water of the New River with an iron

rod held in the other? 2ndly, Whether that commotion was perceptible, if the observer at E, being in all respects as before, the observer at D, standing on wax, took his rod out of the water? 3rdly, Whether that commotion was perceptible to both observers, if the observer at D was placed on wax, and touched the ground with his iron rod in a dry gravelly field at least 300 yards from the water?

To try the first proposition, several explosions were made with the observers at D and E, touching the water, and standing on wax, with their iron rods in the water; when the observers at both stations felt the electrical shock.

To try the second proposition, four explosions were made with the observers at D standing on an originally-electric, and taking his iron rod out of the water, the observer at E as before. In each of these the observer at D felt a small pulsation between his finger and thumb of that hand which held the wire. The observer at E felt each of these as strong as before. The four other explosions were made without any other alteration in the apparatus than that the observer at D stood on the ground about four yards from the water without any communication with it. The observer at E felt the shocks in his arms as before; but the observer at D standing on the ground was shocked in the elbow and wrist of that arm which held the wire, and in both his ancles.

To try the third proposition, eight explosions were made with the observer at D standing on an originally-electric with his rod in the water of the river as before: but the observer at E was placed in a dry gravelly field about three hundred yards nearer the machine than his last station, and about one hundred yards distant from the river. He there stood on the wax, holding the conducting wire in one hand, and touched the ground with an iron rod held in the other. The shock was each time felt by the observer at D, but sensibly weaker than in the former trials; but the observer at E felt them all equally strong with the former; the first four in his arms, when he stood on the wax, and touched the ground with his iron rod; the other four in his arm and ancles, when he stood on the ground without the iron rod.

By the experiments of this day, the gentlemen were satisfied that the dry gravelly ground conducted the electricity as strongly as water, which, though otherwise at first conjectured, they now

found not to be necessary to convey that power to great distances; as well as that, from difference of distance only, the force of the electrical commotion was very little if at all inpaired.

In one instance the circuit was formed from the phial by the observer at D and his wire, a line of ground which reached from the station at D to the broken wire that lay on the ground, and so much of this wire as reached to the short iron rod, which touched the gun-barrel in making the explosions. This induced the gentlemen to conclude, as from many experiments it was manifest, that when the intervening substances conduct electricity equally well, the circuit was performed in the shortest way possible; that when the observers holding their iron rods in the river at D and E were both shocked, the electricity was not conveyed by the water of the river, being two miles in length, but by land, where the distance was only one mile; in which space that power must necessarily pass over the New River twice, through several gravel-pits, and a large stubble field. So that admitting the electricity did not follow the track of the river, the circuit from D to E was at least two miles, viz. somewhat more than one mile of wire, which conducted the electricity from the house to the stations, and another mile of ground the shortest distance between those stations. The same inference was now drawn with regard to the experiments at A, B, and C. in the New River before recited, viz. that as in all of them the distance between the observers was much greater by water than by land, the electricity passed by land from one observer to the other, and not by water.

From the shocks which the gentleman received in their bodies, when the electrical power was conducted by dry sticks, they were of opinion, that from difference of distance simply considered, as far as they had yet experienced, the force was very little if at all impaired. When they stood on originally-electrics, and touched the water or ground with an iron rod, the electrical commotion was always felt in their arms and wrists: when they stood on the ground, and touched either the water or ground with their iron rods, they felt the shock in their elbows, wrists, and ancles; when they stood on the ground without the rod, the shock was always in the elbow and wrist of that hand which held the conducing wire, and in both ancles. The observers here being sensible of the electrical commotion in different parts of their bodies, was ow-

ing in the first instance to the whole of it passing, because the observer stood on wax, through their arms, and through the iron rod; in the second, when they stood on the ground, the electricity passed both through their legs, and through the iron; in the third, when they stood on the ground without either wax or rod, the electricity directed its way through one arm, and through both legs to complete the circuit.

The gentlemen were desirous of closing the present inquiry, by examining not only whether the electrical commotions were perceptible at double the distance of the last experiments in ground perfectly dry, and where no water was near; but also, if possible, to distinguish the respective velocities of electricity and sound. To execute this, required their whole sagacity and address; for they had met with very great difficulties in their last day's operations, where the wire was conducted but little more than a mile; all which could not but be greatly augmented by doubling that distance; because it was necessary, that the house, in which the electrifying machine was placed, should be visible at least at one of the stations; and that the space between that house and the stations, through which the wire was conducted, should be very little intersected by hedges, roads, or foot-paths; neither should the wire in this space be subject to be disturbed by the horses or cattle, which were grazing; nor ought to touch in its passage the trees, or any other vegetables, which at this season of the year were every where luxuriant. To find a place within a convenient distance of London with these requisites was not very easy; but at last Shooter's Hill was pitched on, as the most convenient. As only one shower of rain had fallen during the preceding five weeks, the ground could not but be very dry; and as no water was near, if the electrical commotion was felt by the observers at the stations, it might be safely concluded, that water had no share in conducting it.

Accordingly, August 14, 1747, they met at Shooter's Hill for this purpose. It was here determined to make twelve explosions of the coated phial, with an observer placed at the seven-mile stone, and another at the nine-mile stone, both standing on wax, and touching the ground with an iron rod. This number of explosions was thought the more necessary, as the observers at these stations were not only to examine whether the electricity would be

propagated to so great a distance, but if it were, the observer at the seven-mile stone was by a second watch to take notice of the time lapsed between feeling the electrical commotion, and hearing the report of a gun fired near the machine, as close as might be to the instant of making the explosion; and therefore, to examine this matter with the requisite exactness, this number of explosions should be made.

To execute this, the electrifying machine was placed up one pair of stairs in a house on the west side of Shooter's Hill, and a wire from a short iron rod, with which the gun-barrel was touched in making the explosions, was conducted on dry sticks as before into a field near the seven-mile stone. The length of this wire, exclusive of its turnings, round the sticks, was a mile, a quarter, and eight poles, or 6732 feet. In great part of this space it was found very difficult to support the wire, on account of our scarcely being able to fix the sticks in the strong gravel there almost without any cover of soil; nor could the wire in some places be prevented from toching the brambles and bushes, nor in one field the ripe barley.

Another wire was likewise conducted on sticks from the coated phial to the nine-mile stone. In this space, the soil being a strong clay, the wire was very well secured, and in its whole length did not touch the bushes. The length of this wire was 3868 feet. As much as the place, where the observers were stationed in a corn-field, was nearer the machine than the seven-mile stone, so much were the other observers placed beyond the nine-mile stone, that their distance from each other might be two miles. The 40 feet of wire in these two measures exceeding two miles, was what connected the short iron rod before-mentioned, and the coated phial, with their respective conducting wires.

The observers being placed at their respective stations, the observer at the machine proceeded in making the explosions of the coated phial; by which the observers at the nine-mile stone were very strongly shocked; and they were also felt at the seven-mile stone. This demonstrated that the circuit here formed by the electricity was four miles, viz. two miles of wire, and two miles of ground, the space between the extremities of that wire. A distance without trial too great to be credited! how much farther the electrical commotion will be perceptible, future observations can only determine.

The electrical commotion by the observers near the seven mile stone was but slightly felt; nor could it be otherwise expected, the wire in many parts of its length touching, as was beforementioned, the moist vegetables; which, in as many places as they were touched, formed subordinate circuits. We find, in all other instances, that the whole quantity of electricity, accumulated in the coated phial, is felt equally through the whole circuit, when every part is in a great degree non-electric; so here the whole quantity, or nearly so, determined that way, was felt by the observers at the nine-mile stone; while those at the other station felt so much of their quantity only, as did not go through the vegetables; that is, that proportion only in which iron is a greater non-electric than the vegetables.

Though the electrical commotions, felt by the observers near the seven-mile stone, were not strong; they were equally conclusive in showing the difference between the respective velocities of electricity and sound. The space through which sound is propagated in a given time, has been very differently estimated by the authors who have written on this subject. Roberval gives it at the rate of 560 feet in a second; Gassendus at 1473; Mersenne at 1474; Du Hamel, in the History of the Academy of Sciences at Paris, at 1172; the Academy del Cimento at 1185; Boyle at 1200; Roberts at 1300; Walker at 1338; Sir Isaac Newton at 968; Dr. Derham, in whose measure Mr. Flamstead and Dr. Halley acquiesced, at 1142. But by the accounts since published by M. Cassini de Thury in the Memoirs of the Royal Academy of Sciences at Paris for the year 1738, where cannon were fired at various as well as great distances, under great variety of weather, wind, and other circumstances, and where the measures of the different places had been settled with the utmost exactness, sound was propagated at a medium at the rate only of 1038 French feet in a second. The French foot exceeds the English by 7½ lines, or is as 107 to 114; and consequently 1038 French feet are equal to 1106 English feet. The difference therefore of the measures of Dr. Derham and M. Cassini is 34 French or 36 English feet in a second*. According to the last measure, the velocity of sound,

* M. Cassini de Thury afterwards measured the velocity of sound at Aiguemortes in Languedoc, and found the observations there from those made about Paris vary only half a toise in a second. See Mem. de l'Acad. Royale des Sciences, pour l'anné 1739, p. 126.—Orig.

when the wind * is still, is settled at the rate of a mile, or 5280 English feet in $4\frac{77}{100}''$.

To return to our purpose: the length of the conducting wire from the machine to the observers near the seven-mile stone was 6732 feet; the length of that to the nine-mile stone 3868 feet. The first of these measures only was made use of in the present operations concerning the velocity of electricity. In twelve discharges of the coated phial, which were felt by the observers near the seven-mile stone, and who, by a second watch of Mr. Graham's, measured the time between feeling the electrical commotion and hearing the report of the gun, with the utmost attention and exactness, was at a medium $5\frac{1}{4}$ seconds. And as the gun was distant from these observers 6732 feet, it follows, from the experiments, which have been made on the velocity of sound, that the real instant of the discharge of the gun preceded that of the observers hearing its report, at this time, when the strength of the wind was not so great as to enter into the computation, $6\frac{870}{1000}''$; or preceded the instant when the electrical commotion was felt only $0\frac{837}{1000}''$. But this instant was, from the nature of the experiment, necessarily prior to that of the electrical explosion, which was not made till the fire of the gun was actually seen; and therefore the time between the making of that explosion and its being actually felt by the observer, which must have been less than $0\frac{837}{1000}''$, was really so small, as not to fall under any certain observation, when it is to be distinguished from that which must of necessity be lost, between the firing of the gun and the electrical explosion itself.

In all the experiments where the circuit was formed to any considerable length, though the coated phial was very well charged, the snap at the gun-barrel, on this explosion, was not near so loud as when the circuit is formed in a room; so that a by-stander, though versed in these operations, from seeing the flash and hearing the report, would imagine the stroke at the ends of the conducting wire to be very slight; the contrary of which, when the wire has been properly conducted, has always happened.

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* Dr. Derham found, that when sound was carried against the wind, not only its distance but its velocity was lessened: and in M. Cassini's memoir, there is an experiment, where sound being carried against the wind, which then blew very strong, was retarded near a twelfth part of the usual time in its progress.—Orig.

From a review of these experiments, the following observations may be deduced.

1. That in all the preceding operations, when the wires have been properly conducted, the electrical commotions from the charged phial have only been very considerable, when the observers at the extremities of the wire have touched some substance readily conducting electricity with some part of their bodies.

2. That the electrical commotion is always felt most sensibly in those parts of the bodies of the observers, which are between the conducting wires, and the nearest and the most non-electric substance; or in other words, so much of their bodies as comes within the electric circuit.

3. That on these considerations we infer, that the electrical power is conducted between these observers by any non-electric substances, which happen to be situated between them, and contribute to form the electric circuit.

4. That the electrical commotion has been perceptible to two or more observers at considerable distances from each other, even as far as two miles.

5. That when the observers have been shocked at the end of two miles of wire, we infer that the electrical circuit is four miles, viz. two miles of wire, and the space of two miles of the non-electric matter between the observers, whether it be water, earth, or both.

6. That the electrical commotion is equally strong, whether it is conducted by water or dry ground.

7. That if the wires between the electrifying machine and the observers, are conducted on dry sticks, or other substances non-electric in a slight degree only, the effects of the electrical power are much greater than when the wires in their progress touch the ground, or moist vegetables, or other substances in a great degree non-electric.

8. That by comparing the respective velocities of electricity and sound; that of electricity, in any of the distances yet experienced, is nearly instantaneous.

The gentlemen concerned were still desirous, if possible, of ascertaining the absolute velocity of electricity at a certain distance; because, though last year in measuring the respective velocities of electricity and sound, the time of its progress was found to be very little, yet they were desirous of knowing, small as

that time was, whether it was measurable; and Mr. W. had thought of another method for this purpose.

Accordingly, August 5, 1748, there met at Shooter's Hill for this purpose the president of the Royal Society, and several other gentlemen: when it was agreed to make the electrical circuit of two miles, in the middle of which an observer was to take in each hand one of the extremities of a wire, which was a mile in length. These wires were to be so disposed that, this observer being placed on the floor of the room near the electrifying machine, the other observers might be able in the same view to see the explosion of the charged phial and the observer holding the wires, and might take notice of the time lapsed between the discharging the phial and the convulsive motions of the arms of the observer in consequence of it; as this time would show the velocity of electricity, through a space equal to the length of the wire between the coated phial and this observer.

When all parts of the apparatus were properly disposed, several explosions of the charged phial were made; and it was invariably seen, that the observer, holding in each hand one of the extremities of these wires, was convulsed in both his arms in the instant of making the explosions. Instead of one, four men were then placed, holding each other by the hand near the machine, the first of which held in his right-hand one extremity of the wire, and the last man the other in his left. They were all seen convulsed in the instant of the explosion. Every one who felt it complained of the severity of the shock. It was then tried whether, as the ground was wet, if the explosion was made with the observer holding the extremity of each wire standing on the ground near the window of the house, any difference would arise in the success of the experiment: no difference was found, the observer being shocked in the instant of the explosion as before, in both his arms and across his breast. On these considerations they were fully satisfied, that through the whole length of this wire, being 12,276 feet, the velocity of electricity was instantaneous.

Mr. W. took notice, in a sequel to the experiments relating to electricity*, of an observation of Professor Bose of Wittenberg, *viz.* "that if the electrifying machine is placed on originally-electrics, the man who rubs the globe with his hands, even under

* Printed for C. Davis; London, 1746: 8vo. p. 32.—Orig.

these apparently favourable circumstances, gives no sign of being electrised when touched by an unexcited non-electric. But if another person, standing on the floor, does but touch the globe in motion with the end of one of his fingers, or any other non-electric, the person rubbing is instantly electrised, and that very strongly." This experiment, almost a year since, Dr. Bevis carried further, by placing whatever non-electric touched the globe as a conductor, whether it were a man or a gun-barrel, on originally-electrics. If then, either the man who rubbed the globe, or he who only held his finger near its equator, were touched by any person standing on the floor, a snapping from either of them was perceptible on that touch.

Mr. W. offers a solution of this phenomenon, and then gives another to the same purport, from Mr. Franklin of America:—

At this time (says Mr. W.) I am the more particular concerning the solution of this singular appearance, as Mr. Collinson, a worthy member of this society, has received a paper concerning electricity from an ingenious gentleman, Mr. Franklin, a friend of his in Pennsylvania. This paper, dated June 1, 1747, I very lately perused, by favour of our most worthy president. Among other curious remarks, there is a like solution of this fact: for though this gentleman's experiment was made with a tube instead of a globe, the difference is no-ways material. As this experiment was made, and the solution given on the other side of the Atlantic Ocean, before this gentleman could possibly be acquainted with our having observed the same fact here, and as he seems very conversant in this part of natural philosophy, I take the liberty of laying before you his own words:

"1. A person standing on wax, and rubbing the tube, and another person on wax drawing the fire; they will both of them, provided they do not stand as to touch one another, appear to be electrised to a person standing on the floor; that is, he will perceive a spark on approaching each of them with his knuckle. 2. But if the persons on wax touch one another during the exciting of the tube, neither of them will appear to be electrised. 3. If they touch one another after exciting the tube and drawing the fire as aforesaid, there will be a stronger spark between them, than was between either of them and the person on the floor. 4. After such a strong spark neither of them discover any electricity.

"These appearances we attempt to account for thus: we suppose that electrical fire is a common element, of which every one of these three persons has his equal share before any operation is begun with the tube. A, who stands on wax, and rubs the tube, collects the electrical fire from himself into the glass; and his communication with the common stock being cut off by the wax, his body is not again immediately supplied. B, who stands on wax likewise, passing his knuckle along near the tube, receives the fire which was collected by the glass from A; and his communication with the common stock being cut off, he retains the additional quantity received. To C, standing on the floor, both appear to be electrised: for he, having only the middle quantity of electrical fire, receives a spark on approaching B, who has an over quantity, but gives one to A, who has an under quantity. If A and B approach to touch each other, the spark is stronger; because the difference between them is greater. After such touch, there is no spark between either of them and C, because the electrical fire in all is reduced to the original equality. If they touch while electrising the equality is never destroyed, the fire only circulating. Hence have arisen some new terms among us. We say, B (and bodies alike circumstanced) is electrised positively; A, negatively; or rather, B is electrised plus, A minus. And we daily in our experiments electrise plus or minus, as we think proper. To electrise plus or minus, no more needs be known than this; that the parts of the tube or sphere that are rubbed, do in the instant of the friction attract the electrical fire, and therefore take it from the thing rubbing. The same parts immediately, as the friction on them ceases, are disposed to give the fire they have received to any body that has less. Thus you may circulate it, as Mr. Watson has shown*; you may also accumulate or subtract it on or from any body, as you connect that body with the rubber, or with the receiver, the communication with the common stock being cut off."

The solution of this gentleman, in relation to this phenomenon, so actually corresponds with that which I offered very early last spring, that I could not help communicating it.

In bodies having the power of readily conducting electricity, this seems to depend very little on their specific gravity, simply

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* See my Sequel, p. 64.—Orig.

considered: metals for instance, and water, are in a great degree non-electrics, and consequently conduct electricity the best of any substances that have yet fallen under our notice; whereas the calxes of metals, though very dense bodies, and very greatly more so than water, prevent in a great degree the quick propagation of the electrical power. So that a phial coated within and without with ceruse, *i. e.* the calx of lead, and electrised, did not, on the application as usual of one hand to the external surface, and touching the prime conductor with the other, occasion any shock, or make any explosion, more than the simple stroke from the prime conductor. The same observation holds good with regard to red lead, litharge, and lunar caustic or the calx of silver, none of which snap when electrised. For the same reason, filings of iron, which are rusty, *i. e.* have their surfaces converted into a calx, are much less proper to be put in glasses to make the Leyden experiment, than those that are not; inasmuch as these last cause a much louder explosion than the first.

Mr. W. procured a glass jar as large as possible, so that the glass might be very thin; the height of which was twenty-two inches, the periphery forty-one. This was covered within and without, leaving a margin of an inch at top, with leaf-brass. As much of the internal surface as was covered amounted to 1129 square inches. But the difficulty he met with in procuring this glass, was sufficiently recompensed by the great increase of the explosion from it, when fully electrised, and discharged in the same manner as before. The report was vastly louder; all the attendant phænomena greatly exceeded any thing of this kind he was before acquainted with. As the quantity of metal within this jar did not exceed two drachms, this experiment gives further weight to his opinion in regard to the manner of increasing the effects of the Leyden experiment; and from what the phænomena of that surprising experiment principally proceed; viz. not from the volume of the prime conductor, nor from the quantity of non-electrical matter contained in the glass, but from the number of points of non-electrical contact both within and without-side of the glass, and from the density of the matter constituting those points. It must be observed that cæteris paribus, the electrical explosion is greater from hot water included in glasses, than from cold; and from these glass jars warmed, than when they are cold.

The explosions from the large glasses just mentioned fully electrised, as well as from small ones under the same circumstances, will not be considerable, unless the circuit be completed; that is, unless some matter, non-electric in a considerable degree, and in contact with the coatings of the phials, is brought into contact, or nearly so, with such non-electrics as communicate with the matter contained in the phials themselves. When indeed the circuit can be completed, the explosion from the large glasses is prodigious; the whole quantity of electricity accumulated, or nearly so, being discharged in an instant. But the fact is otherwise if the circuit is not completed, and the iron rod in the mouth of one of these phials is touched by a non-electric (the hand of a man for instance) not in contact with the tail-wire: for then there will be no explosion, no shock; but the person approaching his finger near the iron rod, will see a succession of small sparks, more intensely red than that large one seen when the phials explode at once; and the person making the experiment will feel a very pungent pain, but confined to that finger which touches the iron rod. This succession of sparks continues till the electricity accumulated in the phials is nearly exhausted. So that the explosion from any given quantity of electricity, accumulated as before-mentioned, is greater or less in proportion to the time expended in making that explosion: in like manner as a given quantity of grained gunpowder rammed hard in a pistol, is almost instantaneously fired, and that with a great report; when the same quantity of gunpowder rubbed fine, and rammed hard, takes a considerable time in burning as a squib, and makes no explosion.

From what he has advanced, it may possibly be conjectured, that the electrical effluvia occupy only the surfaces of bodies electrised; as we found that a very small body of matter, distributed under a very large surface, would occasion a greater accumulation of electricity, than a much more considerable quantity of matter under a less. But that the electricity occupies the whole masses of bodies electrised, and passes through their constituent parts, Mr. W. thinks is clearly demonstrated by the following experiment.

He enveloped an iron rod, about three feet in length, with a mixture of wax and resin, leaving free from this mixture only one inch at each end. This iron was warmed, when thus fitted, that the whole of its surface where it was intended might be covered. This

rod, when electrised at one of its ends, snapped as strongly at the other, as though it was without wax and resin. This could not have happened from the electricities passing along the surface of the iron rod, because there it was prevented by the originally-electrics, and consequently must of necessity pass through it.—Again, a phial of water in the experiment of Leyden can be electrised, and may be caused to explode, though the wire, touching the water in the phial in making that experiment, be run through a wax stopple, exactly fitted to the mouth of the phial.

He caused a glass tube, open at each end, and about two feet and a half long, to be capped with brass cemented to the ends of the tube. In the centre of each of these caps was fastened a slender brass rod; and these were disposed so in the tube, as to come within half an inch of each other. When the tube was properly suspended in silk lines, with one of its extremities near a glass globe in motion, the brass work at both ends snapped equally strong. As the electricity could not pass along the surface of this tube warmed and wiped clean, this effect could not have happened, unless the electricity pervaded the substance of the brass caps. On touching the brass at the end of the tube most remote from the electrifying machine, the snaps from one of the brass rods within the tube to the other were seen to correspond with the snaps without. More experiments of this kind might be added, but these he presumes are sufficient to show, that the electricity occupies the whole masses of non-electric bodies electrised.

Mr. W. mentions a series of experiments he had made in vacuo; from the comparison of which with the experiments in open air, it appears that our atmosphere, when dry, is the agent by which, with the assistance of other electrics per se, we are enabled to accumulate electricity in and upon non-electrics; that is, to communicate to them a greater quantity of electricity than they naturally have: hence also we see, that on the removal of the air, the electricity pervades the vacuum to a considerable distance, and manifests its effects on any non-electrics, which terminate that vacuum: and by these means that originally-electric bodies, even in their most perfect state, put on the appearance of non-electrics, by becoming the conductors of electricity.

[*Phil. Trans. Abr.* 1747-8.

2. *The same Subject continued.*

By the same.

Mr. Watson laid before the Royal Society * an account of what had been done by some gentlemen, in order to ascertain the respective velocities of electricity and sound; from which it appeared, that through a space measuring 6732 feet, the electricity was perceptible in a quantity of time less than $\frac{837}{1000}$ of a second. But the gentlemen concerned were desirous, if possible, of ascertaining the absolute velocity of electricity at a certain distance; and a method had been thought of, by which this might be determined with great exactness.

Accordingly, August 5, 1748, there met at Shooter's Hill for this purpose, the president of the R. S. the Rev. Mr. Birch, the Rev. Dr. Bradley, astronomer royal, James Burrow, Esq. Mr. Ellicot, Mr. George Graham, Richard Graham, Esq. the Rev. Mr. Lawrie, Charles Stanhope, Esq. and Mr. W. who were of the Royal Society; also Dr. Bevis, and Mr. Grischow, jun. a member of the Royal Academy of Sciences at Berlin.

It was agreed to make the electrical circuit of two miles; in the middle of which an observer was to take in each hand one of the extremities of a wire, which was a mile in length. These wires were to be so disposed, that this observer being placed on the floor of the room near the electrical machine, the other observers might be able in the same view to see the explosion of the charged phial, and the observer holding the wire; and might take notice of the time lapsed between the discharging the phial and the convulsive motions of the arms of the observer in consequence of it; as this time would show the velocity of electricity, through a space equal to the length of the wire between the coated phial and the observer.

The electrifying machine was placed in the same house as it was last year. We then found ourselves, says Mr. W. greatly embarrassed by the wire's being conducted by the side of the road, which we were compelled to, on account of the space necessary for the measuring of sound; but so great a distance from the machine was

* See the preceding article.

not now wanted, though the circuit through the wire was intended to be at least two miles. We had discovered, by our former experiments, that the only caution now necessary was, that the wires conducted on dry sticks should not touch the ground, nor each other, nor any non-electrical in a considerable degree, in any part of their length; if they did not touch each other, the returns of the wire, be they ever so frequent, imported little, as the wire had been found to conduct electricity so much better than the sticks. It was therefore thought proper to place these sticks in a field fifty yards distant from the machine. The length of this field being eleven chains, or 726 feet, eight returns of the wire from the top to the bottom of the field, made somewhat more than a mile, and sixteen returns more than two miles, the quantity of wire intended for the electricity to pass through to make the experiment.

We had found last year, that on discharging the electrified phials, if two observers made their bodies part of the circuit, one of which grasped the leaden coating of the phial in one hand, and held in his other one extremity of the conducting wire; and if the other observer held the other extremity of the conducting wire in one hand, and took in his other the short iron rod with which the explosion was made; on this explosion, they were both shocked in the same instant, which was that of the explosion of the phial. If therefore an observer, making his body part of the circuit, was shocked in the instant of the explosion of the charged phial in the middle of the wire, no doubt would remain of the velocity of electricity being instantaneous through the length of that whole wire. But if, on the contrary, the time between making the explosion, and seeing the convulsions in the arms of the observer holding the conducting wires, was great enough to be measured, we then should be able to ascertain its velocity to the distance equal to half the quantity of wire employed only, let the manner of the electricity's discharging itself be what it would.

To make the experiment, the same phial filled with filings of iron, and coated with sheet-lead, which was used last year, was placed in the window of the room near the machine, and was connected to the prime conductor by a piece of wire. To the coating of this phial a wire was fastened; which being conducted on dry sticks to the before-mentioned field, was carried in like manner to the bottom; and being conducted thus from the bottom of the field

to the top, and from the top to the bottom seven other times, returned again into the room and was held in one hand of an observer near the machine. From the other hand of this observer another wire, of the same length with the former, was conducted in the same manner, and returned into the room, and was fastened to the iron rod with which the explosion was made. The whole length of the wires, allowing ten yards for their turns round the sticks, amounted to two miles and a quarter and six chains, or 12,276 feet.

When all parts of the apparatus were properly disposed, several explosions of the charged phial were made; and it was invariably seen, that the observer holding in each hand one of the extremities of these wires was convulsed in both his arms in the instant of making the explosions.

Instead of one, four men were then placed, holding each other by the hand near the machine, the first of which held in his right hand one extremity of the wire, and the last man the other in his left. These also were all seen convulsed in the instant of the explosion. Every one who felt it complained of the severity of the shock.

On these considerations we were fully satisfied, that through the whole length of this wire, being 12,276 feet, the velocity of the electricity was instantaneous.

[*Id.*

SECTION III.

Atmospherical Electricity.

Air is one of those bodies which have received the name of *electric*, because they are capable of being positively or negatively charged with electric matter. It not only contains that portion of electricity which seems necessary to the constitution of all terrestrial bodies, but it is liable also to be charged negatively or positively when electricity is abstracted or introduced by means of conducting bodies. These different states must occasion a variety of phænomena, and in all probability contribute very considerably to the various combinations and decompositions which are continually going on in air. The electrical state of the atmosphere, then, is a point of considerable importance, and has with great propriety oc-

cupied the attention of philosophers ever since Dr. Franklin demonstrated that thunder is occasioned by the agency of electricity.

1. The most complete set of observations on the electricity of the atmosphere were made by Professor Beccaria of Turin. He found the air almost always positively electrical, especially in the day time and in dry weather. When dark or wet weather clears up, the electricity is always negative. Low thick fogs rising into dry air carry up a great deal of electric matter.

2. In the morning, when the hygrometer indicates dryness equal to that of the preceding day, positive electricity obtains even before sunrise. As the sun gets up, this electricity increases more remarkably if the dryness increases. It diminishes in the evening.

3. The mid-day electricity of days equally dry is proportional to the heat.

4. Winds always lessen the electricity of a clear day, especially if damp.

5. For the most part, when there is a clear sky and little wind, a considerable electricity arises after sunset at dew falling.

6. Considerable light has been thrown upon the sources of atmospherical electricity by the experiments of Saussure and other philosophers. Air is not only electrified by friction like other electric bodies, but the state of its electricity is changed by various chemical operations which often go on in the atmosphere. Evaporation seems in all cases to convey electric matter into the atmosphere; and Saussure has ascertained, that the quantity of electricity is as much increased when water is decomposed, as when water is dropped on a red hot iron. On the other hand, when steam is condensed into vesicular vapour, or into water, the air becomes negatively electric. Hence it would seem that electricity enters as a component part into water; that it separates when water is decomposed or expanded into steam, and is reunited when the steam is condensed again into water.

Farther, Mr. Canton has ascertained that dry air, when heated, becomes negatively electric, and positive when cooled, even when it is not permitted to expand or contract: and the expansion and contraction of air also occasion changes in its electric state.

Thus there are four sources of atmospheric electricity known: 1. Friction; 2. Evaporation; 3. Heat and cold; 4. Expansion and contraction: not to mention the electricity evolved by the

melting, freezing, solution, &c. of various bodies in contact with air.

7. As air is an electric, the matter of electricity, when accumulated in any particular strata, will not immediately make its way to the neighbouring strata, but will induce in them changes similar to what is induced upon plates of glass or similar bodies piled upon each other. Therefore if a stratum of air be electrified positively, the stratum immediately above it will be negative, the stratum above that positive, and so on. Suppose now that an imperfect conductor were to come into contact with each of these strata, we know, from the principles of electricity, that the equilibrium would be restored, and that this would be attended with a loud noise, and with a flash of light. Clouds which consist of vesicular vapours mixed with particles of air are imperfect conductors; if a cloud therefore come into contact with two such strata, a thunder-clap would follow. If a positive stratum be situated near the earth, the intervention of a cloud will, by serving as a stepping-stone, bring the stratum within the striking distance, and a thunder-clap will be heard while the electrical fluid is discharging itself into the earth. If the stratum be negative, the contrary effects will take place. It does not appear, that thunder is often occasioned by a discharge of electric matter from the earth into the atmosphere. The accidents, most of them at least, which were formerly ascribed to this cause, are now much more satisfactorily accounted for by Lord Stanhope's *Theory of the Returning Stroke.* Neither does it appear that electricity is often discharged into the earth, as the effects of few thunder-storms are visible upon the earth; that it is so sometimes, however, is certain.

In examining and detailing this curious phænomena, there is one remark entitled to particular attention:—it is this, that, during every discharge of electricity, whether natural or artificial, through air, some change similar to combustion undoubtedly takes place. The light and the peculiar smell with which all electrical discharges are accompanied demonstrate this; for no light is perceptible when electricity is discharged in a vacuum. What the change is which electricity produces in air, or how it produces it, are questions which, in the present state of our knowledge, are altogether insoluble. But the very extraordinary galvanic phænomena which at present occupy the attention of philosophers

promise not only to throw light upon this important subject, but to demonstrate a much closer connection between chemistry and electricity than has hitherto been suspected.

[*Thomson.*

CHAP. XLIII.

ELECTRICITY OF THUNDER AND LIGHTNING.

SECTION I.

General History of this curious and interesting Discovery.

THERE is no subject in natural history that has more attracted or more deserved to attract the attention of philosophers, than the cause of Thunder and Lightning. The magnificence, power and splendour of these combined meteors—the tremendous sound—the brilliant and rapid corruscation, and the awful effects produced without any visible instrumentality, have all concurred in fixing the mind in all ages upon these stupendous phænomena.

Among the Greek philosophers the sources of thunder and lightning were separated from each other. The former was ascribed to a variety of causes, of which Lucretius enumerates not less than ten, the principal of them being the shock of clouds against clouds, and of winds against winds, meeting together from adverse points. The latter was attributed to an accumulation of pure etherial particles of elementary fire, of exquisite minuteness, concentrated in the cloud or clouds, whence the thunder-storm issued, and there creating a gas or vapour of a peculiar and individual quality *, an idea strongly congruous with the discoveries of modern times.

It was long afterwards supposed, that both phænomena had one common origin, and proceeded from sulphureous, nitrous, bituminous or other inflammable vapours ascending from the bowels of

* See Good's Lucretius and Notes, book vi. v. 98, and following.

the earth, and fermenting together in the atmosphere. Thomson, that he might be sure of being right, enlists the whole of these into service; first describing the ascent of inflammable substances into the atmosphere; and then telling us that they there gradually

> *Ferment;* till by the *touch etherial* rous'd,
> The *dash of clouds*, or *irritating war*
> *Of fighting winds*, while all is calm below,
> They furious spring. SUMMER, 1103.

Within the last half century, however, philosophers have confined themselves to the *etherial touch* alone; to the accumulation of particles of elementary fire of a peculiar quality, to which alone the school of Epicurus ascribed the origin of lightning, and they have abundantly succeeded in proving, that this peculiar quality is that of the electric fluid; or, in other words, that thunder and lightning are altogether electrical phænomena.

The philosophers of the middle of the last century had not proceeded far in their experiments and enquiries on this subject, before they perceived the obvious analogy between lightning and electricity, and they produced many arguments to evince their identity. But the method of proving this hypothesis beyond a doubt was first proposed by Dr. Franklin, who, about the close of the year 1749, conceived the practicability of drawing lightning down from the clouds. Various circumstances of resemblance between lightning and electricity were remarked by this ingenious philosopher, and have been abundantly confirmed by later discoveries, such as the following: flashes of lightning are usually seen crooked and waving in the air; so the electric spark drawn from an irregular body at some distance, and when it is drawn by an irregular body, or through a space in which the best conductors are disposed in an irregular manner, always exhibits the same appearance; lightning strikes the highest and most pointed objects in its course, in preference to others, as hills, trees, spires, masts of ships, &c.; so all pointed conductors receive and throw off the electric fluid more readily than those that are terminated by flat surfaces: lightning is observed to take and follow the readiest and best conductor; and the same is the case with electricity in the discharge of the Leyden phial; whence the doctor infers, that in a thunder-storm, it would be safer to have one's clothes wet than

dry: lightning burns, dissolves metals, rends some bodies, sometimes strikes persons blind, destroys animal life, deprives magnets of their virtue, or reverses their poles; and all these are well-known properties of electricity.

But lightning also gives polarity to the magnetic needle, as well as to all bodies that have any thing of iron in them, as bricks, &c. and by observing afterwards which way the magnetic poles of these bodies lie, it may thence be known in what direction the stroke passed. Persons are sometimes killed by lightning without exhibiting any visible marks of injury; and in this case Signior Beccaria supposed that the lightning does not really touch them, but only produces a sudden vacuum near them, and the air rushing violently out of their lungs to supply it, they cannot recover their breath again: and in proof of this opinion he alleges, that the lungs of such persons are found flaccid; whereas these are found inflated when the persons are really killed by the electric shock; his hypothesis, however, was controverted by Dr. Priestley; and a better theory, that of the returning stroke, has since been introduced by Lord Stanhope to explain the phænomenon.

To demonstrate, by actual experiment, the identity of the electric fluid with the matter of lightning, Dr. Franklin contrived to bring lightning from the heavens, by means of a paper kite, properly fitted up for the purpose, with a long fine wire string, hence called an electrical kite, which he raised when a thunder-storm was perceived to be coming on: and with the electricity thus obtained, he charged phials, kindled spirits, and performed all other such electrical experiments as are usually exhibited by an excited glass globe or cylinder. This happened in June 1752, a month after the electricians in France, in pursuance of the method which he had before proposed, had verified the same theory, but without any knowledge of what they had done. The most active of these were Messrs. Dalibard and Delor, followed by M. Mazeas and M. Monnier.

In April and June 1753, Dr. Franklin discovered that the air is sometimes electrified negatively, as well as sometimes positively: and he even found that the clouds would change from positive to negative electricity several times in the course of one thunder-gust. This curious and important discovery he soon perceived was capable of being applied to practical use in life, and in consequence he

proposed a method, which he soon accomplished, of securing buildings from being damaged by lightning, by means of conductors.

Nor had the English philosophers been inattentive to this subject: but, for want of proper opportunities of trying the necessary experiments, and from some other unfavourable circumstances, they had hitherto failed of success. Mr. Canton, however, succeeded in July 1752; and in the following month, Dr. Bavis and Mr. Wilson observed nearly the same appearances as Mr. Canton had done before. By a number of experiments Mr. Canton also soon after observed, that some clouds were in a positive, while some were in a negative state of electricity; and that the electricity of his conductor would sometimes change, from one state to the other, five or six times in less than half an hour.

But Sig. Beccaria discovered this variable state of thunder-clouds, before he knew that it had been observed by Dr. Franklin or any other person; and he has given a very exact and particular account of the external appearances of these clouds. From the observations of his apparatus within doors, and of the lightning abroad, he inferred that the quantity of electric matter in a common thunder-storm, is inconceivably great, considering how many pointed bodies, as spires, trees, &c. are continually drawing it off, and what a prodigious quantity is repeatedly discharged to or from the earth. This matter is in such abundance, that he thinks it impossible for any cloud or number of clouds to contain it all, so as either to receive or discharge it. He observes also, that during the progress and increase of the storm, though the lightning frequently struck to the earth, the same clouds were the next moment ready to make a still greater discharge, and his apparatus continued to be as much affected as ever; so that the clouds must have received at one part, in the same moment when a discharge was made from them in another. And from the whole he concludes, that the clouds serve as conductors to convey the electric fluid from those parts of the earth that are overloaded with it, to those that are exhausted of it. The same cause by which a cloud is first raised, from vapours dispersed in the atmosphere, draws to it those that are already formed, and still continues to form new ones, till the whole collected mass extends so far as to reach a part of the earth where there is a deficiency of the electric fluid, and where the electric matter will discharge itself on the earth. A

channel of communication being thus produced, a fresh supply of electric matter is raised from the overloaded part, which continues to be conveyed by the medium of the clouds, till the equilibrium of the fluid is restored between the two places of the earth. Beccaria observes further, that a wind always blows from the place from which the thunder-cloud proceeds; and that the sudden accumulation of such a prodigious quantity of vapours must displace the air, and repel it on all sides. Indeed, many observations of the descent of lightning, confirm his theory of the manner of its ascent; for it often throws before it the parts of conducting bodies, and distributes them along the resisting medium, through which it must force its passage; and upon this principle, the longest flashes of lightning seem to be made, by forcing into its way part of the vapours in the air. One of the chief reasons why these flashes make so long a rumbling is, that their production by the vast length of a vacuum made by the passage of the electric matter: for although the air collapses the moment after it has passed, and the vibration, on which the sound depends, commences at the same moment; yet when the flash is directed toward the person who hears the report, the vibrations excited at the nearer end of the track, will reach his ear much sooner than those from the more remote end; and the sound will, without any echo or repercussion, continue till all the vibrations have successively reached him.

How it happens that particular parts of the earth, or the clouds, come into the opposite states of positive and negative electricity, is a question not absolutely determined: though it is easy to conceive that when particular clouds, or different parts of the earth, possess opposite electricities, a discharge will take place within a certain distance; or the one will strike into the other, and that in the discharge a flash of lightning will be seen. Mr. Canton queries whether the clouds do not become possessed of electricity by the gradual heating and cooling of the air; and whether air suddenly rarefied may not give electric fire to clouds and vapours passing through it, and air suddenly condensed receive electric fire from them.—Mr. Wilcke supposes, that the air contracts its electricity in the same manner that sulphur and other subtances do, when they are heated and cooled in contact with various bodies. Thus, the air being heated or cooled near the earth, gives electricity to the earth, or

receives it from it; and the electrified air, being conveyed upward by various means, communicates its electricity to the clouds.

It has since been observed by Lord Mahon, now Earl Stanhope, that damage may be done by lightning, not only by the main stroke and lateral explosion, but also by what his lordship calls THE RETURNING STROKE; by which is meant, as we shall notice more fully in a subsequent article, the sudden and violent return of that part of the natural share of electricity gradually expelled from some body or bodies within the range of the main stroke, by the additional passage of the electrical atmosphere discharged from the thunder cloud.

[*Phil. Trans. Rozier. Payne. Editor.*

SECTION II.

Invention and Curious Properties of the Electrical Kite.*

1. Letter from Benjamin Franklin, Esq. to Mr. Peter Collinson, F.R.S. dated Philadelphia, October 1, 1752.

As frequent mention is made, in the public papers from Europe, of the success of the Philadelphia experiment, for drawing the electric fire from clouds, by means of pointed rods of iron erected on high buildings, &c. it may be agreeable to the curious to be informed, that the same experiment has succeeded in Philadelphia, though made in a different and more easy manner, which any one may try, as follows:—

Make a small cross of two light strips of cedar, the arms so long as to reach to the four corners of a large thin silk handkerchief, when extended; tie the corners of the handkerchief to the extremities of the cross, so you have the body of a kite, which, being properly accommodated with a tail, loop, and string, will rise in the air like those made of paper; but this, being of silk, is fitter to bear the wet and wind of a thunder-gust without tearing. To the top of the upright stick of the cross is to be fixed a very sharp-pointed wire, rising a foot or more above the wood. To the end of the twine next the hand, is to be tied a silk ribbon; and where the twine and silk join, a key may be fastened.

* See further on this subject, section v. 1.

The kite is to be raised when a thunder gust appears to be coming on, and the person who holds the string must stand within a door, or window, or under some cover, so that the silk ribbon may not be wet; and care must be taken that the twine does not touch the frame of the door or window. As soon as any of the thunder-clouds come over the kite, the pointed wire will draw the electric fire from them; and the kite, with all the twine, will be electrified; and the loose filaments of the twine will stand out every way, and be attracted by an approaching finger.

When the rain has wet the kite and twine, so that it can conduct the electric fire freely, you will find it stream out plentifully from the key on the approach of your knuckle. At this key the phial may be charged; and from electric fire thus obtained spirits may be kindled, and all the other electrical experiments be performed, which are usually done by the help of a rubbed glass globe or tube, and thus the sameness of the electric matter with that of lightning completely demonstrated.

[*Phil. Trans.* 1752.

2. *The same subject continued.*

By W. Watson, Esq. F.R.S.

After the communications received from several correspondents in different parts of the continent, acquainting us with the success of their experiments last summer, in endeavouring to extract the electricity from the atmosphere during a thunder-storm, in consequence of Mr. Franklin's hypothesis, it may be thought extraordinary that no accounts have been yet laid before the Society of our success here from the same experiments. That no want of attention therefore may be attributed to those here, who have been hitherto conversant in these inquiries, he states, that though several members of the Royal Society, as well as himself, did, on the first advices from France, prepare and set up the necessary apparatus for this purpose, they were defeated in their expectations, by the uncommon coolness and dampness of the air here, during the whole summer. They had at London only one thunder-storm; *viz.* on July 20; and then the thunder was accompanied with rain, so that by wetting the apparatus the electricity was dissipated too soon to be perceived on touching those parts of the apparatus

which served to conduct it. This in general prevented verifying Mr. Franklin's hypothesis; but Mr. Canton was more fortunate, as appears by the following letter from him to Mr. Watson, dated from Spital-square, July 21, 1752:—

"I had yesterday, above five in the afternoon, an opportunity of trying Mr. Franklin's experiment of extracting the electrical fire from the clouds; and succeeded by means of a tin tube, between three and four feet in length, fixed to the top of a glass one, of about eighteen inches. To the upper end of the tin tube, which was not so high as a stack of chimneys on the same house, I fastened three needles, with some wire; and to the lower end was soldered a tin cover to keep the rain from the glass tube, which was set upright in a block of wood. I attended this apparatus as soon after the thunder began as possible, but did not find it in the least electrified, till between the third and fourth clap; when applying my knuckle to the edge of the cover, I felt and heard an electrical spark; and approaching it a second time, I received the spark at the distance of about half an inch, and saw it distinctly. This I repeated four or five times in the space of a minute, but the sparks grew weaker and weaker, and in less than two minutes the tin tube did not appear to be electrified at all. The rain continued during the thunder, but was considerably abated at the time of making the experiment."

Mr. Wilson likewise of the Society, to whom we are much obliged for the trouble he has taken in these pursuits, had an opportunity of verifying Mr. Franklin's hypothesis. He informed Mr. W. by a letter from near Chelmsford, in Essex, dated August 12, 1752, that on that day about noon, he perceived several electrical snaps, during, or rather at the end of, a thunder-storm, from no other apparatus than an iron curtain-rod, one end of which he put into the neck of a glass phial, and held this phial in his hand. To the other end of the iron he fastened three needles with some silk. This phial, supporting the rod, he held in one hand, and drew snaps from the rod with a finger of his other. This experiment was not made on any eminence, but in the garden of a gentleman, at whose house he then was.

Dr. Bevis observed, at Mr. Cave's, at St. John's gate, nearly the same phenomena as Mr. Canton.

Trifling as the effects here mentioned are, when compared with

those which we have received from Paris and Berlin, they are the only ones that the last summer here has produced; and as they were made by persons worthy of credit, they tend to establish the authenticity of those transmitted from our correspondents.

Id.

SECTION III.

Considerations to prevent Lightning from doing Mischief to great Works, high Buildings, and large Magazines.*

By Mr. Wilson, F.R.S.

Long experience, since the discovery by Dr. Franklin, has now established a truth among philosophers, that lightning, like the electric fluid, passes more freely through iron, copper, and other metals, than through dry wood, stone, or marble. Instances of this truth are innumerable: and to be convinced of it, we need only trace the late violent effects of lightning on St. Bride's church, and the houses in Essex-street, &c. For on examining these buildings, it appears that there are certain thick bars of iron, through which the lightning has passed, without producing any visible effects; and, on the contrary, in certain parts where the junctions of those bars with the stone, or wood, are made, there the lightning, rushing from the iron, has broke the stone to pieces, and shivered the wood. From the like experience we also learn, that if the iron is too slender for conducting the lightning, it is either dashed into pieces, or exploded like gunpowder; just in the same manner as we are able, by the electric power, to break and dissipate in vapour a very slender wire. Bars of metal, of a proper thickness, and conveniently disposed, seem therefore necessary for the security of such buildings.

It is to be noted, that the mischiefs caused by lightning are not always owing to its direction from the clouds to the buildings, or other eminences, and thence to the earth; but sometimes, on the contrary, from the earth, buildings, and other eminences, to the clouds. For the principle on which its direction depends, appears to arise from the restoration of a certain equilibrium, in a subtile

* See farther on this subject the articles in Section v.

and elastic fluid, previously disturbed by various causes. Now, according to the laws of elastic fluids, the endeavour to restore the equilibrium of such a fluid, will be in that direction where the resistance to its passage happens to be the least. On this principle we therefore see a necessity, either to open a passage for it to go freely through, by placing certain bars of metal properly, or to stop the passage of the fluid through such buildings entirely. The last method would be dangerous to put in practice; because, if high buildings were so secured, the lightning would then attack the lower buildings, which are far more numerous, and probably would destroy a greater number of people, cattle, &c. Whereas, if the first method is preferred, the high buildings will then tend to protect the lower ones more effectually; and may with propriety be considered as so many pipes to carry off the lightning quietly, either from the earth to the clouds, or from the clouds to the earth. And that several proper conductors are necessary to carry off the lightning, more readily than some of the accidental or partial conductors in a large town are capable of, appears from this; that we are able to collect small quantities of the electric fluid, with a slender apparatus in our hands only; whilst it is exposed in the street, garden, or other open place, during the hovering of such clouds as occasion violent lightning.

From repeated observations of this kind, there is reason to believe, that the quantity of lightning at particular times, is so very great, that it would be dangerous to invite it to any buildings, and that unnecessarily, in the most powerful manner we are able; by suffering the several conductors to end in a point at the top. On which account it is apprehended, that pointed bars, or rods, of metal, ought always to be avoided. And as the lightning must visit us some way or other, from necessity, to restore the equilibrium, there can be no reason to invite it at all; but, on the contrary, when it happens to attack our buildings, we ought only so to contrive our apparatus, as to be able to carry the lightning away again by such suitable conductors, properly fixed, as will very little, if at all, promote any increase of its quantity.

To attain which desirable end, in some degree at least, it is proposed, that the several buildings remain as they are at the top; that is, without having any metal above them, either pointed or not, by way of a conductor. On the inside of the highest part of

such building, and within a foot or two of the top, it may be proper to fix a rounded bar of metal, and to continue it down along the side of the wall to any kind of moisture in the ground. But if the building happens to be mounted with an iron spindle, for supporting a vane, or other ornament, and it should not be convenient to have it taken away, then the bar of metal ought to communicate with that spindle. And as to the diameter of such a metal bar, it will probably depend on the height of the building; for it is apprehended the great church of St. Paul's, to complete the partial conductors (which are the metallic cross, ball, gallery, dome, &c.) and secure it effectually, would require a bar of metal two inches diameter, if not more; and a building like the British Museum, one considerably less. But it appears there is no occasion for any at that repository, as it is already provided, though from accident, like many other buildings, with very effectual conductors. The copings of the roof, and the several spouts, which are continued from it into the ground, being all of lead.

That conductors ought to be thicker than is generally imagined, seems to appear from a late instance taken notice of in St. Bride's church, by Mr. Delaval, and Dr. Watson, where an iron bar, $2\frac{1}{2}$ inches broad, and half an inch thick, or more, was bent and broken asunder by the violence of the lightning. The Eddystone Lighthouse, which stands on a rock, surrounded by the sea, the work of Mr. Smeaton, was thought to be an object very likely to suffer by lightning; and the more so, as the top of it consisted of a copper ball, two feet in diameter, with a chimney of the same metal, passing through it down to the second floor, but no farther. Directions were therefore given to make a communication of metal from the lowest part of the copper chimney down to the sea; which was executed accordingly about the year 1760, or soon after the building was finished. Now if, instead of the copper ball, a pointed bar of metal had been put in its place, or above it, and communicated with the conducting matter below, there is no saying what might be the consequence of so powerful an invitation, to an edifice thus particularly situated.

Since the former part of this paper was communicated to the R. S., that is, on the 5th of August, 1764, I received the following account from Captain Dibden, commander of a merchant ship, who says, that in the year 1759, he was taken by the French, and

carried prisoner to Fort Royal, in Martinico. That in removing him thence some time after, and on foot, to St. Pierre, which is about twenty miles, his conductors, or guard, stopped at a small chapel, five miles from the last place, to shelter themselves from the heavy rain which fell during a violent thunder-storm. That the chapel had no steeple or tower belonging to it, but stood on an eminence, with three or four poor low houses near it. That soon after they were thus sheltered, a violent flash of lightning struck two soldiers dead, who had been leaning against the wall of the chapel, between two buttresses, and not far from the rest of the company, being all on the leeward side of the chapel. That it made an opening in the wall about four feet high, and about three feet broad, and in that part only against which they rested.

That Captain Dibden, along with other persons, entered at this hole immediately after, to see if any other damage had been done to the chapel. That they observed a square bar of iron near the hole, and on the ground, about four feet long, and $1\frac{1}{4}$ inch thick, making an angle with the wall, as they suppose, to support the upper part of an inclined tombstone, which was also thrown down and broken to pieces. That this bar was joined in the middle to one end of another bar, about one foot long, and one inch thick, which laid horizontally, and, passing to the wall, had been there fastened with lead. That the lightning, in rushing along the inclined bar, had wasted or reduced its thickness in some places very considerably, insomuch that it looked like a burnt poker which had been long used; and broke the bar into two pieces, about an inch above the joining of the lesser bar, the ends of which had a burnt flaky appearance. That the other parts of the bar were changed in colour to a grey, or whitish hue, resembling iron after it has been exposed to a violent heat and then suffered to cool. That the horizontal bar had also undergone an extraordinary change by the lightning, but particularly at that end next the wall of the chapel, it being reduced from one inch in diameter to the size of a slender wire, but tapering towards the wall. That when the soldiers rested against the wall, their heads were about the same height with the shortest bar; and, from what he can recollect, were very near being opposite to that end which was inserted in the wall. That the two soldiers were forced from the wall at the same instant by the lightning; so that their feet, which were one yard or more from it,

were nearest to the wall, and their heads the farthest off. That their flesh appeared very black. That their clothes were burnt and scorched in many parts, and their belts shrivelled up, as if they had been exposed to a large fire. That Captain Dibden, and other people, felt a disagreeable kind of an electric shock, at the same instant that the soldiers were killed.

Captain Dibden gave an account also, that he was lately at Virginia, 1763: that the inhabitants of Norfolk had changed their opinions in respect to fixing of wires and small rods of iron on the tops of their houses; from the frequent instances they have lately had of their being melted, or destroyed, by the violence of the lightning: and that now they adopted, in their stead, rods of iron from half an inch thick to three-fourths of an inch thick, or more. That those rods ended in a point at the top, and extended from three feet above their houses down to the ground; and that many houses had one of these conducting irons at each end. The Capt. added, that though the pine trees are considerably higher than the oaks in the American woods, yet the oaks are the oftenest attacked by the lightning: and that he does not remember any oaks growing among the pine trees, when the latter have suffered by lightning, which must be owing to the greater resistance arising from the unctuous nature of the pine trees.

[*Phil. Trans.* 1764.

SECTION IV.

Thunder-storms remarkable from their violence, or the peculiarity of their effects.

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1. *Strange effect of Thunder and Lightning on Wheat and Rye in the Granuries of Dantzic.*

By M. Christopher Kirby.

You doubtless know how much this city is famed for its numerous and convenient granaries, it being the repository of all sorts of grain the fruitful kingdom of Poland affords. In those granaries are laid up chiefly wheat and rye, in parcels of twenty to

thirty and sixty lasts in one chamber, according to its size, and the dryness of the corn; which they turn over three, four, five, six times a week, as need requires, to keep it sweet and fit for shipping. Now it happened, that about the latter end of March and April last, we had much and violent thunder and lightning, which had this unhappy effect on all the parcels of wheat and rye of the last year's growth, that, though over night they were dry, sweet, and fit for shipping, the next morning they had lost all these good qualities, and were become clammy and stinking, and consequently unfit to be shipped away for the present; so that the owners were forced to cause it to be turned over two or three times a day, and yet it required six weeks, if not longer, before it was recovered.

This is a thing which often happens to corn that has not lain in the granary a whole year, or not sweat thoroughly in the straw before it is thrashed out. An accident little noted, yet in my judgment worth the enquiring into; for, though the alterations caused by thunder in liquors, be taken notice of, and probable reasons given for them, yet I judge this somewhat more abstruse, and therefore more worth while to be considered.

[*Phil. Trans.* 1673.

2. *Extraordinary Thunder-Storm near Aberdeen.*

In a letter to Dr. George Garden.

This happened July 24, 1695. The day was clear and pleasant, till about half past three, afternoon, when some rain fell; then two claps of thunder, rather moderate; then fell a heavy shower of hail, accompanied with a third clap of thunder, very tremendous, attended with great damage to the houses and people. In a school were the master and fifteen boys; the building was perforated and shattered in several places, illumined as with a strong and sudden fire, attended with a suffocating and sulphureous smell and dark smoke. The persons were all either struck down, or badly wounded and bruised. Four were killed outright, the rest recovered in due time. In the parts where they were struck, which was chiefly about the shoulders, the flesh was much discoloured, and the clothes there cut or perforated, to appearance as if eaten by rats.

[*Id.* 1696.

3. *Thunder-storm near Halifax, December 22, 1698: fatal to a young man.*

By Ralph Thoresby, Esq. F.R.S.

Jeremiah Skelton, of Warley, near Halifax, Yorkshire, observing a storm coming, hastened to gather in some of the corn which was out at a farm of his father's in the Cold Edge, about a quarter of a mile from their own dwelling; while at this work, bringing in burden and casting it upon the barn-floor, the tempest began as he came forth again; whereupon he stepped aside for shelter within the barn door, and while there, was struck with a dreadful flash of fire. The young man was a sad spectacle, being beaten down, quite dead, and many stones about him; he was laid upon his face, wholly naked, save a small part of his shirt about his neck, and a piece of a stocking on one foot, and so much of a coat-sleeve as covered the wrist of one arm; his shoes driven from his feet, one not to be found, and the other split; his hat not to be found after search, and the rest of his garments torn into small shreds, and cast at considerable distances, one piece from another; the hair of his head and beard singed, as if with a candle, and a little hole below his left eye, which was probably made with the fall upon a stone, for there was a great breach made on the barn, the door tops, both of stone, broken, and the wall above them fallen, with the slate and water-tables.

[*Id.*

4. *Singular effects of a Storm on a House and its Furniture at New Forge, Ireland.*

By Samuel Molyneaux, Esq. S. Phil. Soc. Dubl.

Mrs. Close gave Mr. Molyneaux the following account of the effects of thunder and lightning, on her house at New Forge in the county of Down, in Ireland, on Aug. 9, 1707: she observed, that the whole day was close, hot, and sultry, with little or no wind stirring, till towards the evening; that there was a small breeze with some mizzling rain, which lasted about an hour; that as the air darkened after sun-set, she saw several faint flashes of lightning, and heard some thunder-claps, as at a distance; that between ten

and eleven o'clock both were very violent and terrible, and so increased, and came on more frequently until a little before twelve o'clock; that one flash of lightning and clap of thunder came both at the same time, louder and more dreadful than all the rest, which, as she thought, shook and inflamed the whole house; and being sensible at that instant of a violent strong sulphureous smell in her chamber, and feeling a thick gross dust falling on her hands and face as she lay in bed, she concluded that part of her house was thrown down by the thunder, or set on fire by the lightning; that arising in this fright, she called up her family, and candles being lighted, she found her bed-chamber, and the kitchen beneath it, full of smoke and dust; and the looking-glass in her chamber was broken.

The next day she found that part of the cornish of the chimney, which stood without that gabel-end of the house where her chamber was, had been struck off; that part of the coping of the splay of the gabel-end itself was broken down, and twelve or sixteen of the shingles on the adjoining roof were raised or ruffled, but none shattered or carried away; that part of the ceiling in her chamber beneath those shingles was forced down, and part of the plaster and pinning stones of the adjoining wall was also broken off and loosened, the whole breach being sixteen or twenty inches broad; that at this place there was left on the wall a smutted scar or trace, as if blacked by the smoke of a candle, which pointed downwards towards another place on the same wall, where a like breach was made, partly behind the place of the looking-glass; that the boards on the back of a large hair trunk, full of linen, standing beneath the looking-glass, were forced in, and splintered as if by the blow of a smith's sledge; that two-thirds of the linen within this trunk were pierced or cut through, the cut appearing of a quadrangular figure, and between two or three inches over; that one end of the trunk was forced out, as the back was driven in; that at about two feet distance from the end of the trunk, where the floor and the side-wall of the house joined, there was a small breach made in the plaster, where a small chink or crevice was to be seen between the side board of the floor and the wall, so wide that a man could thrust his fingers down; and that just beneath this, in the kitchen, the ceiling was forced down, and some of the plaster of the wall broken off; that exactly under this there stood a large tub or vessel

of wood, inclosed with a crib of brick and lime, which was broken and splintered all to pieces, and most of the brick and lime-work about it scattered about the kitchen.

I observed that the looking-glass was broken with such violence, that there was not a piece of it to be found of the size of a half-crown; that several pieces of it were sticking like hail-shot in the chamber door, which was oak, and on the other side of the room; that several of the edges and corners of some of the pieces of the broken glass were tinged of a light flame colour, as if heated in the fire; that the curtains of the bed were cut in several places, supposed to be done by the pieces of the glass; that several pieces of muslin and wearing linen, left on the large hair trunk, were thrown about the room, no way singed or scorched, and yet the hair on the back of the trunk, where the breach was made, was singed; that the uppermost part of the linen within the trunk was not touched, and the lowermost parcel, consisting of more than 350 ply of linen, was pierced through, of which none was any wise smutted, except the uppermost ply of a table-cloth that lay over all the rest; that there was a yellow tinge or stain, perceivable on some part of the damaged linen, and that the whole smelt strongly of sulphur; that the glass of two windows in the bed-chamber above, and two windows in the kitchen below, was so shattered, that there was scarcely one whole pane left in any of them; that the pewter, brass, and iron furniture in the kitchen were thrown down, and scattered about, particularly a large girdle about twenty pounds weight, that hung upon an iron hook near the ceiling, was found lying on the floor; that a cat was found dead next morning in the kitchen, with its legs extended as in a moving posture, with no other sign of being hurt, than that the fur was singed a little about the rump.

It was further remarkable, that the wall, both above and below a little window in the same gabel-end, was so shattered, that the light could be seen through the crevices in the wall; and that upon a large stone on the outside of the wall, beneath this window, was a mark, as if made by the stroke of a smith's sledge, and a splinter of the stone was broken off, of some pounds weight. I was further informed, that from the time of that great thunder-clap, both the thunder and lightning diminished gradually, so that in an hour's time all was still and quiet again. [*Id.* 1708.

5. *Storm at Samford-Courtney in Devonshire, Oct. 7, 1711, producing great damage to the Church.*

By John Chamberlayne, Esq. F.R.S.

In the parish of Samford-Courtney, near Oakhampton in Devon, on the 7th of October, about three or four o'clock in the afternoon, there was a great darkness as the minister was catechising the children, so that he could hardly see with spectacles: several people being in the church porch, of a sudden a great fire-ball fell in among them, and threw them some one way, some another; but no one was hurt. The ringers in the belfrey said, they never knew the bells go so heavy, and were obliged to leave off: and being very weary, and looking out of the belfrey into the church, they saw four fire-balls a little larger than a man's fist, which of a sudden broke to pieces, so that the church was full of fire and smoke. One man received a blow in the neck, which caused him to bleed both at nose and mouth. He says, that the fire and smoke went up into the tower, and broke a large beam on which one of the bells hung, and the gudgeon breaking, the bell fell on the floor. It likewise carried away one of the pinnacles of the tower next the town, and threw some of the stones near a barn door at a pretty distance from the church, and has done some damage to the barn at one end. The chimney of the house was removed in such a manner by the thunder and lightning, that the people were surprised that it continued to stand.

[*Id.* 1712.

6. *Effects of Lightning in Northamptonshire.*

By the Rev. Jos. Wasse.

We are told by Mr. Jessop, in a former number of the Transactions, that what the common people call fairy circles, are occasioned by lightning; but I think it has not yet been observed, that they continue visible fifty years, and that no composition of use in fire-works will produce near so lasting an effect as I have experienced. There seems to be something here, which sulphur and nitre will hardly account for. Does it depend on the great quantity of the matter discharged, or the violence with which it is impelled? The ground is nowise torn up, and the grass is only a little

blasted; whence it would seem its force is nearly spent: whereas, when the burst is near us, the effect is like that of a petard, as appears from the following instance.

At Mixbury, on July 3, one William Hall, about sixty years of age, was found dead in a hard gravelly field, with five sheep, which lay round him at about thirty yards distance; of which that only which lay nearest him had a visible wound through the head. The shepherd lay partly on his side; the upper part of his head was terribly fractured, and his right knee was out of joint; he had a wound in the sole of his foot, towards the heel; his right ear was cut off, and beaten into his skull, and blood flowed out of that part upon the ground. All his clothes and shirt were torn into small pieces, and hung about him; but from the girdle downwards they were carried away entirely, and scattered up and down the field, particularly the soles of a pair of new strong shoes were rent off. His hat was torn to pieces, a hand-breadth of it was full of irregular slits, and in some few places cut as if with a very sharp penknife, and a little singed in the upper part. His beard and the hair of his head were mostly close burnt off. The iron buckle of his belt was thrown forty yards off, and a knife in the right side pocket of his breeches was broken in pieces, not melted, and the handle split. Near his feet were two round holes, about a yard deep and five inches diameter, like the perforation of a mortar shell fired perpendicularly upwards, when it falls down again. About the time this accident happened, a tradesman of the town observed a sort of fire-ball, as large as a man's head, to burst in four pieces near the church. Two persons at Aynho were a little hurt at the same time, and one of them struck down to the ground, who says, he thought he was knocked down with a beetle. Mr. Wasse himself heard the hiss of a ball of fire, almost as large as the moon, which flew over his garden from S.E. to N.W.

Both the above-mentioned holes were almost perpendicular for half a yard, and after that grew narrower: in both of them, the matter divided into two parts, and formed horizontal cavities about three inches diameter. In one was found a very hard glazed stone, of about ten inches long, six wide, and four in thickness, cracked in two; others it could not pierce, but was turned here and there out of its course, but left not the least blackness, or other discolouring any where. As to the knife, it was not the blade but the

handle and the hinge which were shivered in pieces. Near the wounded sheep, the ground was torn up near two yards round.

One James Marshal of the same town said, that in the middle of the same storm he received a blow on his hat, which rattled like shot through the branches of a tree; it beat in the crown a little, without penetrating it: he staggered, and was giddy for two days afterwards. Two of his sons were at the same instant both struck down to the ground, and stunned a little, but presently came to themselves, and had no wound. Query, whether this may not be accounted for, by supposing the flame to rarefy the air, and make a sort of vacuum about one, into which when it returns again, it gives the likeness of a stroke with a beetle, as he expressed it. Perhaps a wind-gun, with compressed air, would have the same effect, and might easily be tried on a dog, or such like animal.

[*Id.* 1725.

7. *Great Mischief to a Household in Carmarthenshire.*

By Mr. Evan Davies.

December 6, 1729, in the afternoon, there happened terrible thunder and lightning, which alarmed the whole neighbourhood: and about four o'clock, as a woman was carrying a pail of water into the house, there broke such a violent clap of thunder, that she and three of her children were very surprisingly struck, and instantly deprived of their senses, so that they lay miserable monuments of the terrible shock; and it seems they lay weltering in their blood, before they recovered and were able to creep to the bed, till the next neighbour happened to come in (the husband being then abroad at his day-labour) to assist them. The lightning it seems struck at the east end, near the foundation, into the hearth, and split in two a thick stone of about half a yard in breadth beyond the fire, and shattered one half into small splinters, which shot into the flesh, and did the most hurt. About twenty-four or more of those stones were, from time to time, taken out of their wounds. It appears, that afterwards it forced its way out through the wall on the south side, within the compass of the hearth, where it made a terrible breach from top to bottom, and removed the stones from the foundations, making a deep hole perpendicular in the earth, that one might thrust in a staff to the top.

The partitions in the house were moved out of their place; and a chest full of corn forced down towards the door, some yards from the place where it stood. The bucket the woman had in her hand, and other wooden vessels in the house, were all or most of them shattered; dishes and spoons, &c. blown off, and after some days, found and gathered in the garden, on the north side of the house, split and broken; and many more disorders were committed.

The woman has quite lost her left eye. She was speechless for a week or nine days, and could not swallow. She has lately had a few stones come out from the roof of the mouth, under the tongue, and other parts inwardly: the tip of her tongue was taken off, by which she is still lisping; three of the fore teeth of the under jaw broken, with the lower lip slit, but now pretty well healed; two of the right hand fingers quite off, and the colour of that hand still like a flame of fire, as if there were yet remaining some igneous particles in it. She has a terrible gash on that shoulder between the joints, that an egg might be contained in it, besides three or more bruises on the arm down to the wrist, that she is not able to lift it up, without the help of the other hand; besides several other wounds and bruises, over great part of her body. A boy had his hair all singed, his face and breast all scorched with blisters like bladders running from the raw flesh, with several stones taken out from his body and legs; and two other small children suffered greatly; so that the wounds are reckoned to be thirty at least between the mother and children, and many splinters of bones taken out of them. Only one girl, about ten years old, that stood at a distance next the door, escaped, having her clothes only singed, but no hurt done her. They smelled so strongly of the sulphur for some days, that one could hardly go near them. They are now, however, freed from any grievous pain to complain of; so that they go about.

[*Id.* 1730.

8. *Melancholy and fatal Effects of a Storm near Ludgvan, in Cornwall.*

By the Rev. W. Borlase, F. R. S. dated Feb. 1, 1753.

This storm was on December 20 preceding. The first traces in the parish of Maddern, were an incision, or scratch, made in the

turf, about three inches wide, and two deep, where the lightning coming up from the south-west, passing through the bank, and issuing out from the bank in three streams, which united again, and turned away to the north. About ten paces to the north of these breaches, there are more marks of the same kind, but not in the same direction; for the lightning here came from the north-west, and, passing upwards, the furrow, which it had made, grew wider, and somewhat deeper, as it gained on the hill, especially where it met with bank or stone; and some banks were five feet wide, which had their tops untouched, but were pierced through as with a bullet. This second furrow was (as all the rest) not in a straight line, but in a vermicular direction, and with its turnings led to a karn, or ledge of flat rocks, striking off many splinters from it, and in some places making a perforation through it. There were made also furrows ten inches wide, and a foot deep; besides which, were several places in the hill which had holes about a foot wide, and six or eight inches deep, and several clods cut thin and clear off from the ground: which shows, that as this lightning went like darts through banks and stones, and tore up the ground in many places like a ploughshare, so in other places it spread into a horizontal thin edge, which scooped up and carried off the little unevenness of the turfy ground. The whole workings of this lightning were in length about a furlong from west to east.

The first thunder-clap was succeeded, in less than a quarter of an hour, by another, which broke at a village, in the parish of Gullval, called Trythal, about a mile and a half to the south-west of Moelfra hill, and was attended with the following melancholy accidents:

Thomas Olivey, a respectable farmer, had returned from the field, about a quarter before twelve o'clock, and had all his family round him in the kitchen, except his daughter, who was in the hall. There was a pan over the fire in the kitchen-chimney, full of boiling water. The farmer was sitting by the fire, and his wife on a bench before it; their only son, twenty-three years of age, was standing at the window, when it lightened much, and the first clap of thunder followed. This was so violent that the back door of the kitchen, which opened to the north, quivered. The farmer called to his son, and desired him not to stand so near the window, lest the lightning should hurt his eyes; on which the young man

removed from the window, backwards, into the corner of the room, and sat down. The lightning came from the west-north-west, and falling on the stack of the kitchen-chimney, which was about four feet square, and as much in height, of hewed stone, carried it clear off from the house, and threw it into a pool of water twenty feet distant. In the chamber over the kitchen, directly beneath the top of the chimney, there was a little closet boarded in; all the boards were broken to pieces, the timbers of the roof shattered; as also the bedstead in that chamber; of the chamber-partition two planks were forced, a large cloaths-press thrown, and the south windows of the chamber-floor (excepting one casement) all broken, and blown out. From the top of the chimney, and chamber-floor, it descended into the kitchen below, where the family was: the farmer saw no lightning, nor heard any thunder, after the first clap before-mentioned; but was struck senseless with the first flash, and thrown into the middle of the kitchen, and continued senseless for a quarter of an hour. As soon as he came to himself, he asked, who struck him? but had not the use of his arms; and felt an aching pain, shooting, as he described it, into his bones; and a brand-iron, which hung in the chimney, being thrown down into the pan of water, on the fire, had dashed the boiling water upon him to that degree, that his life was in extreme danger for more than a fortnight after. Mrs. Olivey was struck down before the hearth. Both her shoes, though buckled on as usual, were struck off her feet, but her feet not hurt; and being neither burnt nor senseless, was able to cry out for help, but could not move; for she had no use of her under-limbs for a day and a half.

The farmer's brother was at the end of a long table in the same room, and was only flung against the wall, about three feet distant, not hurt. Mrs. Olivey's sister was near the back door; a plank of this door was started, and beat in: she was struck senseless, and thrown twelve feet off against the settle, which stood against the south wall of the house.

The farmer's son had his coat and waistcoats (for he had two on) torn into shreds, so that it could hardly be distinguished where the pieces had formerly joined; his shirt had a rent two feet long down the back, and was scorched; his left shoe torn from his foot; and the little toe of that foot so nearly cut off, that it hung only by a bit of skin; and he was quite dead. But though reduced to this

lamentable condition, as to his exterior, he was not moved from his seat, nor his face at all changed: his dog was lying at his feet, dead likewise, but never moved.

The farmer's daughter received the shock in the hall; was struck senseless, but revived soon; felt a trembling all over; her feet tickling, and partly benumbed and stiff, as if sleeping; but perceiving in the room a cloud of smoke, and hearing her mother cry, she made haste into the kitchen, which she found full of smoke, stinking like brimstone. The lightning had left a mark quite across the clavel of the kitchen-chimney, about half an inch wide, in an undulating direction, broke through the partitions of the under floor, thrown down the shelves, carried out all the south windows, forced up the stair-case, blown out the north window, missed or spared a clock, which stood close by the window; and being somewhat spent, when it reached the hall, carried out the windows; moved not some Delft basins, which were in the south window, but forced the door of a beaufet, at the end of the hall, an inch and a half inwards; and shook the eastern wall of the house to the very foundation.

The clouds over Moelfra hill, and the village of Trythall (a space of a mile and a half) were so heavily charged with lightning, that here they broke, both the first and the second time, and the thunder-claps were within a few minutes of each other, as being produced but by two portions of one and the same congeries.

The general tendency of this lightning was as the direction of the wind at that time; that is, from the north-west to the east, but where the principal explosions were, as at the hill, and the house, many branches spread off in all directions. Nor were the shapes, in which it operated, less different than its motions. Sometimes, as it appeared to Mr. B. at Ludgvan, it was pointed as a dart, in some places edged as a scythe, now but one thin sheet or stream, then two or three, and then one again. Now it fell as several separate balls of fire, but on the house as a large gush or torrent. It was all fire, yet of different powers, according to the impregnation of its several portions. Subtile and penetrating as the electrical fire, it affected, shocked, and permeated, all the human frame. Some parts of it only scorched wood, but did not melt iron, as with lightning is very common: some tore the leather and clothes; some cut and wounded, and some killed without wound

or rent; and other parts of this lightning again, upon stone, wood, leather, clothes, and flesh, only rushed and forced with the power of air put into a violent agitation. All this happened in this place, and all in an instant: and though the clothes were somewhat singed, as well as torn, and the young man's skin round his waist was also scorched, yet, from the general effects of this lightning in both places, it was rather swift, and irresistibly piercing, than inflammatory. The house stands very high, without tree or hill near it.

[*Id.* 1753.

9. *Effects of Lightning on the Steeple and Church of Lestwithiel, Cornwall.*

By Mr. John Smeaton, F. R. S.

January 25, 1757, above five o'clock in the evening, returning home from the Eddystone works near Plymouth, Mr. S. observed four flashes of lightning, within the space of six or seven minutes, towards the west: but heard no noise of thunder, distance about thirty miles. A few days after, he was informed, that the same evening the lightning had shattered the church of Lestwithiel in a very surprising manner. At the time before-mentioned, the inhabitants were alarmed by a violent flash of lightning, accompanied with thunder so sudden, loud, and dreadful, that every one thought the house he was in was falling upon him, almost every one being within doors, on account of a violent shower of rain which preceded the lightning: so that nobody knew any thing of the mischief done to the church, till it was observed accidentally after the shower.

The steeple is carried up, plain and square, to about forty-nine feet, with a kind of slate-stone rough-cast on the outside, on which is formed a very elegant octagon Gothic lantern, about nine feet high, and on it a stone spire about fifty-two feet high, with a spindle and vane rising about three feet above the stone: so that the whole together was about 113 feet. Each face of the lantern finishes above with a sort of Gothic pediment, with a little pinnacle on each, separated from the body of the spire.

The vane was much bruised, which might be occasioned by the fall; but the socket was rent open, as if it had been burst by gun-

powder; and in such a manner as could not well be occasioned by the fall. Under the spindle that carried the vane, was a bar of much the same size and length, that passed through the centre of several of the uppermost stones successively, to unite them the more firmly together, and was run in with lead: all which surrounding stones were broken off, except one, which, together with the bar, fell down within the tower.

The shell of the spire as far down as thirty-five feet from the top, was no more than seven inches thick, and the courses about the same height: so that scarcely any one stone in the spire could weigh more than thirty or forty pounds; but they were joined together at the ends with mortoise and tenon in a curious manner. Above twenty feet of the upper part was entirely thrown down, and dispersed in all directions; and some pieces were found at the distance of 200 yards. A great many stones fell on the roof of the church breaking the pews, and whatever they fell upon. Six feet still lower the spire was separated, the western half being thrown down; the eastern half was left standing, but disjointed, and in so critical a posture, that it seemed ready to fall every moment: so that this was ordered to be taken down immediately, and likewise to six feet below, the work being found remarkably shattered. The whole of the spire he found much cracked and damaged, but the remainder of the seven inch shell so greatly, that there seemed scarcely a whole joint.

The pediments over every face of the lantern were damaged more or less; but the whole ashlering of that to the N. W. was torn off from the inner wall, to which it was connected. Several of the pediments were damaged, and even stones struck out, where the little pinnacles above them were left standing.

About the top of the lantern is a bell for the clock to strike on: it is hung on a cross-bar, with gudgeons at each end; the whole being suspended to a beam laid across the tower. The cross-bar was so bent, that the clock hammer would not touch the bell by above two inches. This could not be done by the falling of stones, because the beam would defend the bell from receiving any stroke in the direction to which the cross-bar was bent. As to the wire that drew the hammer, not one bit of it could be found.

The bells, four in number, for ringing, hung in the square part of the tower below the lantern, two above and two below: the

wheels of every one were broken to pieces, and one of the iron straps by which they were fastened to the yoke, unhooked. Whether these accidents were occasioned by the lightning or the falling stones, he leaves undetermined. In the floor under the bells was placed the clock, cased up with slight boards. The verge that carries the pallets was bent downwards, as if a ten pound weight had falled ten feet high right upon it. The crutch that lays hold of the pendulum, looked as if it had been cut off by a blunt tool, and heated by the blow, till it was coloured blue at the place where it was cut. It turned at a right angle, and might be about $\frac{4}{10}$ of an inch broad by $\frac{2}{10}$ thick. As to the pendulum which hung pretty near the wall, the upper part of the rod was struck with such violence against the wall, that a sharp impression of it was made in the plaster: and near the upper part of the impression appeared a circular shady ring, of a blackish colour, something like as if a pistol had been discharged of powder, and the muzzle held near the wall. In this story several stones were forced out of the wall. The walls of the belfry or tower were much damaged; several stones driven out, and perforations made in the solid wall, particularly one of fourteen inches square and six inches deep, so truly square and regular, as if cut out by art. All the windows in the church either broken out, or bagged outward.

[*Id.* 1757.

10. *Effects of Lightning on St. Bride's Church, Fleet Street**, *June* 18, 1764.

By Edward Delaval, Esq. F. R. S.

The construction of this spire is somewhat similar to that of an apparatus purposely contrived to draw the lightning from the clouds, as it runs up towards a point, and ends in a metal vane and cross, the figure of which, as well as the materials they consist of, seem calculated to admit the lightning with the least resistance. The first marks of it are seen at the top of the copper cross, which is the highest part of the building; the gilding is by the explosion partly torn off and partly discoloured, so as to differ remarkably

* The next article in the same volume contains an account of serious mischief sustained by various houses in Essex Street, Strand, from the same storm.

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from the rest of the cross where the gilding is very well preserved. Some small pieces of solder are melted; and all this part appears as if it had been exposed to the fire. The lightning seems to have entered here, and to have been conducted thence by an iron spindle twenty feet in length, and two inches in diameter; of which ten feet were surrounded by the copper ball, vane, and cross; and the lower half was inclosed in a groove cut through the middle of the solid stone which composed the upper part of the spire, and rested on the bottom of that groove, which was sunk five inches deep into the lowest of those solid stones: this last mentioned stone being three feet broad and one deep. The interval between the sides of the spindle and the groove made to receive it was filled up by melted lead poured in between them.

The lightning accumulated in the metal, having its passage towards the earth strongly resisted at this place, has in expanding itself formed a hole, by bursting off from the lower part of the spindle the stones contiguous to it on that side. At each of the angles of the metal, the stone on which it rested is cracked, which probably was occasioned by the lightning issuing with greater freedom from those parts, than from the flat surface. No part of the spindle is in the least injured by the lightning, notwithstanding the great quantity which, from its effects, appears to have been accumulated in it*. From hence, as low as the corniche, it seems to have been conducted along the surface of the spire, which was wetted by the rain that had fallen in the morning, before the lightning: and having been accumulated in the iron bars, in discharging itself from them, it has made the greatest explosion at this place.

Under this part the freedom of its passage seems to have been hindered by all the dry stonework underneath, which was defended from the rain by the corniches: and it appears from some experiments which I formerly made †, that dry free-stone, when warmed to a certain degree (which probably does not exceed the heat which the stones of buildings acquire in hot weather) resists the passage of the electric fluid or lightning so strongly, that with plates of

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* In the year 1750 the stones surrounding this spindle were so much damaged, that there was a necessity of taking them down and rebuilding that part of the spire. The cause of this was not known at that time; it is probable that it was occasioned in the same manner as the present accident.—Orig.

† Phil. Trans. abridged, vol. xi. 334.

that stone, instead of glass, I performed the Leyden experiment. Under the corniche, the lightning descended only by leaping from one iron to another; and at every leap its force seems to have been weakened, and at last to have been quite dissipated.

On examining the inside of the steeple, beginning from the top, the first effect of the lightning that appears is a hole in the stone work, beginning immediately above an iron bar which served to support the top of the window or opening, and running upwards towards the two cross iron bars: this, when viewed from the outside of the church, is seen to have spread round most of the lower part of the spire, so that it seems in great danger of falling. The next stroke is about four feet below: at this place four iron bars lie horizontally across the spire, and are tied together by chain bars which are inclosed in the stone work: where the end of one of the cross bars is inserted in the stone, the lightning has burst open a hole, and when the same is viewed at the outside, a great part of the corniche appears to be broken off. Where the two iron bars serving to support the top of the windows meet and are joined together, the lightning accumulated in them has broken off the pier by which they were inclosed. A bar of iron, which served to support the top of the window in the same manner as those last mentioned, twenty-one inches long clear of the stonework, and half an inch thick, is broken; and the stones immediately above it are shattered and disjointed. The sills of two windows of this story are torn off from iron bars which lay beneath them.

An iron bar, No. 1, about 25 inches long, was inclosed nine inches deep in the stone-work of the pier, separating the east arch from the arch next it towards the north: the end of this bar joins at a right angle another bar, No. 2, which is laid across the arch. The lightning accumulated in the iron No. 1, which was inclosed in the stone-work, has burst off all the stone that surrounded it, and part of the pier adjoining. The flaw is continued downwards, meeting with smaller iron cramps in its way. At the next arch, lying immediately under the last mentioned one, an iron was inclosed in the stone in the same manner as the bar at No. 1: the stone is torn off from this iron exactly in the same manner as at No. 1: but the damage has not reached much farther than the stone which was contiguous to, and covered this bar. At the bottom of this arch the sill stone, which covered some cramps of iron, is torn

off from its place. At the next arch under this, the force of the lightning seems to have been much diminished, a small part of one stone only being broken.

From the wall of the west side of the south window of the belfry some stones were thrown down: one chalky stone in particular is reduced into an impalpable powder, and the wall under the west window is almost covered with the powder: this stroke seems to have been directed towards the bells, one of which is very near the place damaged: the bells have not been examined; nor can they, it is said, without danger of shaking the spire by their motion. This is the lowest mark which is left of the effects of the lightning.

In every part that is damaged, the lightning has acted as an elastic fluid, endeavouring to expand itself where it was accumulated in the metal; and the effects are exactly similar to those which would have been produced by gunpowder pent up in the same places, and exploded. Among many other stones thrown to a considerable distance by these explosions, one weighing above 70 pounds was removed 50 yards eastward from the steeple, where it fell through the roof of a house. It is evident that these effects would have been prevented, if a sufficiently large metallic conductor had been extended from the metal at the top of the spire down to the earth, communicating with the other metallic parts of the building that lay in its way. Such a communication seems very necessary in buildings of this form. The iron bars which were fixed in the stone-work of the east arches were struck by the lightning, while those in the arches fronting them on the west side of the same story remained untouched by it. So that probably a conductor communicating with the west arches only, would not have preserved the opposite ones from the damage they have suffered.

When such buildings are exposed to very large clouds replete with lightning, there is no reason to imagine that they will not convey some of their contents to other metallic parts of the building at the same time as to the metal at the top: for though the conductor may be large enough to convey to the ground, from the top, all the lightning that enters that part, yet one such small conductor cannot be supposed to exhaust those immense bodies so quickly, as to disable them from striking at the same time other buildings, or other parts of the same building. A wire, or very small rod of metal, does not seem to be a canal sufficiently large to conduct

so great a quantity of lightning to the earth, especially when any part of it, or of the metal communicating with it, is inclosed in the stone-work: in which case, the application of it would tend to increase its bad effects, by conducting it to parts of the building which it might otherwise not have reached.

Dr. Franklin, from observing that the filleting of gold leaf on the cover of a book conducted the charge of five large jars, reasons that a wire will be sufficient to conduct the lightning from the highest buildings to the earth. But it appears from an experiment of his own, that a much larger body of metal, when inclosed between small plates of thick looking-glass, is not sufficient to conduct a fifth part of such a charge, without being melted, and bursting to pieces the plates of glass. And it is remarkable, that in those parts of the church where the effects of the lightning are most conspicuous, the iron was inclosed in a resisting substance similar to the glass surrounding the gold leaf in that experiment. Wires, instead of conducting the lightning, have often been melted by the explosion. So that, it seems, a conductor of metal less than six or eight inches in breadth, and a quarter of an inch in thickness (or an equal quantity of metal in any other form that may be found more convenient) cannot with safety be depended on, where buildings are exposed to the reception of so great a quantity of lightning. These are the only points in which I have ventured to differ from Dr. Franklin.

[*Id.* 1764.

11. *Singular and fatal Effects of a Thunder-Storm, without Lightning, near Coldstream, Scotland.*

By Patrick Brydone, Esq. F.R.S.

Tuesday, July 19, 1785, was a fine soft morning, thermometer at ten, 68°; about eleven, clouds began to form in the south-east; and between twelve and one there were several flashes of lightning, followed by rolling claps of thunder, at a considerable distance. Soon after however Mr. B. was suddenly alarmed by a loud report, for which he was not prepared by any preceding flash: it resembled the firing of several muskets, so close together, that the ear could hardly separate the sounds, and was followed by no rumbling noise like the other claps. Soon after he was told that a

man and two horses had been struck dead by the thunder, at a small distance from his house. Mr. B. immediately set out, and arrived on the spot in less than half an hour after the accident. The horses were still yoked to the cart, and lying in the same position in which they had been struck down; but the body of the young man had been already carried off by his companion, who soon returned to the place, and described to him how every thing had passed.

They were both servants to Mr. Turnbull, a tenant of the Earl of Home, and were returning home with two carts loaded with coals. James Lauder had the charge of the first cart, and was sitting on the fore part of it. They had crossed the Tweed a few minutes before, at a deep ford, and had almost gained the highest part of an ascent above 65 or 70 feet above the bed of the river. At that instant he was stunned by a loud report, and saw his companion, his horses and cart, fall to the ground. He immediately ran to his assistance, but found him quite dead. His face, he said, was of a livid colour, his clothes were torn to pieces, and he had a strong smell of burning. He immediately emptied his own cart, and carried home Lauder's body to his friends; so that I had not an opportunity of examining it: but Mr. Bell, minister of Coldstream, a gentleman of the most perfect candour and veracity, said, that he had been sent for to announce the fatal event to the young man's parents, and had examined the body; that he found the skin of the right thigh much burnt and shrivelled, and many marks of the same kind over the whole body; but none on the legs, which he imputed to their hanging over the fore-part of the cart at the time of the explosion, and not being in contact with any part of it. His clothes, and particularly his shirt, was very much torn, and emitted a strong smell of burning. The body was buried two days after, without having discovered any symptoms of putrefaction.

Lauder's companion showed the distance between the two carts, which was exactly marked; for his horses had turned round at the time of the explosion, and broke their harness; it was about 24 yards, and Lauder's cart was a few feet higher on the bank, but had not yet reached the summit. Mr. B. now examined the cart, and the spot around it. The horses were black, and of a strong make; they had fallen on the left side, and their legs had made a

deep impression in the dust, which, on lifting them up, showed the exact form of each leg; so that no kind of struggle or convulsive motion had succeeded the fall, but every principle of life seems to have been extinguished in an instant. The hair was much singed over the greatest part of their bodies; but was most perceptible on the belly and legs. Their eyes were already become dull and opaque, and looked like the eyes of an animal which had been long dead. The joints were all supple; and he could not perceive that any of the bones were either softened or dissolved, as it has been alledged sometimes happens to animals killed by lightning. The left shaft of the cart was broken; and the splinters had been thrown off in many places, particularly where the timber of the cart was connected by nails, or cramps of iron. Many pieces of the coal were likewise thrown out to a considerable distance, all round the cart; and some of them had the appearance of coal which had lain some time on a fire. He also gathered up the fragments of Lauder's hat, which had been torn to innumerable small pieces; as well as part of his hair, which was strongly united to some of the fragments which had composed the crown of the hat. About $4\frac{1}{2}$ feet behind each wheel of the cart, was an odd appearance in the ground; a circular hole of about twenty inches in diameter, the centre of which was exactly in the tract of each wheel. The earth was torn up, as if by violent blows of a pick-axe, and the small stones and dust were scattered on each side of the road. The tracks of the wheels were strongly marked in the dust, both behind and before these holes, but were completely obliterated for upwards of a foot and a half on these spots. This led Mr. B. to suspect, that the force which had formed them must likewise have acted strongly on the wheels; and on examination, he found evident marks of fusion on each of them. The surface of the iron to the length of about three inches, and the whole breadth of the wheel, had become of a bluish colour, had entirely lost its polish and smoothness, and had the appearance of drops incompletely formed on its surface; these were of a roundish form, and had a sensible projection. To ascertain whether these marks were occasioned by the explosion which had turned up the ground, he pushed back the cart on the same tracks which it had described on the road; and found, that the marks of fusion answered exactly to the centre of each of the holes; and that, at the instant of the explosion, the

iron of the wheels had been sunk deep in the dust. They had made almost half a revolution after the explosion, which might be occasioned by the falling down of the horses, which pulled the cart a little forward. On examining the opposite part of the wheels, or that part which was at the greatest distance from the earth, no mark of any kind was observable. The broken earth still emitted a smell something like that of ether. The ground was remarkably dry, and of a gravelly soil.

It would appear, that this great explosion had, in an instant, pervaded every substance connected with the cart, the wheels of which had probably conducted it from the ground. They had been completely wetted but a few minutes before, as well as the legs and bellies of the horses, and might perhaps be the reason why the hair on these parts was much more burnt than on the rest of their bodies. However, the two horses had already walked over this electrical mine, without having produced any effect; and had not the cart followed them might have escaped without hurt. He examined all their shoes, but could not perceive the least mark on any of them, nor was the earth broken where they had trodden. But the cart was deeply laden, and the wheels had penetrated much farther into the ground.

The equilibrium between the earth and the atmosphere seems at this instant to have been completely restored; for no further appearance of thunder or lightning was observed within the hemisphere; the clouds dispelled, and the air resumed the most perfect tranquillity; but how this vast quantity of electric matter could be discharged from the one element into the other without exhibiting any appearance of fire, he pretends not to examine. The fact however appears certain; and when he was mentioning it as a singular one, a gentleman told him, that the shepherd of St. Cuthbert's farm, on the opposite bank of the Tweed, had been an eye-witness of the event, and gave a different account of it. Mr. B. immediately went to the farm, found the shepherd, and made him conduct him to the spot whence he had observed it, and desired him to give an account of what had happened. He was looking, he said, at the two carts going up the bank, when he was stunned by a loud report, and at the same instant saw the first of the carts fall to the ground, and observed that the man and horses lay still, as if dead. He said, he saw no lightning, nor appearance of fire, whatever;

but observed the dust to rise at the place; that there had been several flashes of lightning some time before from the south-east, whereas the accident happened to the north-west of where he stood. The distance, in a right line across the river, might be between two or three hundred yards. He was sensible of no shock, nor uncommon sensation of any kind.

Several other phenomena happened on that day, probably all proceeding from the same cause; some of which Mr. B. mentions. The shepherd belonging to the farm of Lennel-hill was in a neighbouring field, tending his flock, when he observed a lamb drop down; and said, he felt at the same time as if fire had passed over his face, though the lightning and claps of thunder were then at a great distance from him. He ran up immediately, but found the lamb quite dead; nor did he perceive the least convulsive motion, nor symptom of life remaining, though the moment before it appeared to be in perfect health. He bled it with his knife, and the blood flowed freely. This happened about a quarter of an hour before the explosion which killed Lauder; and it was not above three hundred yards distant from the spot. He was only a few yards from the lamb when it fell down. The earth was not torn up, nor did he observe any dust rise.

Thomas Foster, a celebrated fisher in Coldstream, and another man, were standing in the middle of the Tweed, fishing for salmon with the rod, when they suddenly heard a loud noise; and, turning round to see from whence it came, they found themselves caught in a violent whirlwind, which felt sultry and hot, and almost prevented them from breathing. It was not without much difficulty they could reach the bank, where they sat down, exhausted with fatigue, and greatly alarmed: however it lasted but a very short time, and was succeeded by a perfect calm. This happened about an hour before the explosion.

A woman making hay near the banks of the river, fell suddenly to the ground, and called out to her companions, that she had received a violent blow on the foot, and could not imagine from whence it came. Mr. Bell, our minister, nephew of Thomson the poet, and possessed of all the candour and ingenuity of his uncle, said, that, walking in his garden, a little before Lauder's accident, he several times felt a sensible tremor in the ground. He also said, that he had observed on Lauder's body a zig-zag line, of about an

inch and a quarter broad, which extended from his chin down to his right thigh, and had followed nearly the line of the buttons of his waistcoat. The skin was burnt white and hard.

These are all the circumstances, says Mr. B. I have been able to collect that are well authenticated, and I shall not trouble you with reports that are not. From the whole it would appear, that the earth had acquired a great superabundance of electrical matter, which was every where endeavouring to fly off into the atmosphere. Perhaps it might be accounted for from the excessive dryness of the ground; and for many months, the almost total want of rain, which is probably the agent that nature employs in preserving, or in restoring, the equilibrium between the other two elements. But I shall not pretend to investigate the causes: all I wanted, was to give some account of the effects.

P. S. I cannot send away this letter without adding, in a postscript, that on Friday the 11th of August last, early in the morning, we had a pretty smart shock of an earthquake. I was awaked by it, and felt the motion most distinctly for four or five seconds at least. It appeared as if the bed had been pulled gently from side to side several times. The motion was nearly north north-west and south-east, as far as I could judge from the motion of the bed. The windows were violently shaken, and made a great noise, which I believe was mistaken by many people for a noise accompanying the earthquake. I immediately rose to look at my watch, and found it twenty minutes after two. It was a dead calm, the morning close and warm, with a small drizzling rain, and though the moon was but two days past the full, so dark that I could not perceive the hour without striking a light. It was felt in almost every house in this neighbourhood, and all the way from this country to the west coast of the island, where it seems to have been more violent than here: but to the east of this place it was very little felt.

Perhaps it may not be improper to mention the state of the weather for some time before and after this event, as it may possibly have had some influence on it. The drought was very great till the 22d of July, when it rained a little; and this was repeated, though in small quantities, and generally accompanied by high winds, till Thursday the 27th, when it blew the most violent tempest I ever remember in this country. The young crop of turnips,

in many fields, were blown out of the ground, and almost entirely destroyed. The pease became brown as if withered, and so did the leaves of the forest trees on that side which was opposed to the blast. Vast clouds of dust were raised from the dry fields and roads, which looked like smoke, and had the appearance at a distance as if many villages had been on fire all over the country. The water too was raised from the surface of the river, and carried quite away by the violence of the hurricane, forming small clouds in the air, which we traced to a great distance. The great violence of this tempest lasted but a few hours, and at night it fell calm. The barometer was little affected, and stood at $29\frac{1}{2}$ inches. The wind was early west, veering sometimes a little to the north. From this time we had a course of very fine weather, the wind constantly in the west points, till the time of the earthquake (which happened on what is called the last of the dog-days), when it changed to the south-east, and brought us five of the worst days I ever remembered to have seen at that season; it rained almost incessantly, with a cold easterly wind, and the sun did not once appear till the morning of Wednesday the 16th, after which we had again a course of fine weather. I examined the barometer at the time of the earthquake, but did not find that it had been sensibly affected. It rose a little on that morning; but this I imputed to the wind having changed to the east.

[*Id.* 1787.

12. *Theory of the returning Stroke, in Explanation of the preceding Phænomena.*

By the Right Hon. Charles Earl Stanhope, F. R. S.

No storm of lightning has ever produced effects more curious to contemplate than those related by Mr. Brydone, in his letter to the president of this Society. That account contains facts of such consequence, and so perfectly inexplicable by the commonly received principles of electricity, that it undoubtedly deserves particular attention. It appears, that a man, James Lauder, sitting on the fore part of a cart drawn by two horses, was suddenly struck dead, as also the horses that he was driving, and that the cart itself was much injured by electrical fire, though no lightning fell at or near the place where this accident happened.

Now few facts of this kind have ever been better authenticated than this is. It appears first, that a man, who was sitting on the fore-part of another cart, only twenty-four yards behind the cart that was struck, "had Lauder, his cart and horses, full in view when they fell; he was stunned by a loud report, and saw his companion, his horses and cart, fall to the ground; he immediately ran to his assistance, but found him quite dead; he perceived no flash or appearance of fire." It also appears, that another man, a shepherd of St. Cuthbert's farm, was also a witness of this event, was distant from Lauder "between two and three hundred yards, and was looking at the two carts, when he was stunned by a loud report, and at the same instant saw the first of the carts fall to the ground. He saw no lightning, nor appearance of fire whatever." The concurrent testimony of these two men is confirmed by Patrick Brydone, Esq. who lives at a small distance from the spot where Lauder was killed; and Mr. Brydone relates, that a storm appeared far off; and that he, and some company in his house, were "suddenly alarmed by a loud report, for which they were not prepared by any preceding flash." There is the greater weight to be given to this account of Mr. Brydone, as it so happened, that he was just then "observing the progress of the storm, at an open window, in the second story of his house," and making the company "observe, by a stop-watch, the time that the sound took to reach them."

That the death of Lauder, and of the horses, was not occasioned by any direct main stroke of explosion from a thunder-cloud, either positively or negatively electrified, Lord S. thinks is evident; since no lightning whatever passed from the clouds to the earth, or from the earth to the clouds, at the place where they were killed. It is equally evident, and for the very same reason, that they were not deprived of life by any transmitted main stroke of explosion, either positive or negative. It is also obvious, he adds, that the lateral explosion was not the cause of this mischief; for the lateral explosion does always proceed immediately from the main stroke itself; and therefore there can exist no lateral explosion, in the case when there is no main stroke whatever.'

Lord S. thinks, from the different circumstances of this case, that the effects produced proceeded from electricity; and that no electrical fire did pass immediately either from the clouds into the cart,

&c. or from the cart, &c. into the clouds. From the circular holes in the ground, of about twenty inches in diameter, the respective centres of which were exactly in the track of each wheel, and the corresponding marks of fusion on the iron of the wheels, which marks answered exactly to the centre of each of the holes; it is evident, he says, that the electrical fire did pass, from the earth to the cart, or from the cart to the earth, through that part of the iron of the wheels which was in contact with the ground. From the splinters that had been thrown off, in many places, particularly where the timber of the cart was connected by nails or cramps of iron, and from the various other effects mentioned in Mr. Brydone's paper, it is further evident, that there was a violent motion of the electrical fluid in all, or at least in different parts of the cart, and of the bodies of the man and horses, though there was no lightning.

Wonderful as these combined facts may appear, and uncommon as they certainly are in this country, they are however easy to be explained by means of that particular species of electrical shock, which I have distinguished in my Principles of Electricity, published in 1779, by the appellation of the "electrical returning stroke:" and though at the same time I wrote that Treatise, I had it not in my power to produce any instance of persons or animals having been killed in the very peculiar manner since related in Mr. Brydone's paper; I did, however, from my experiments mentioned in that book, venture to assert, with confidence, that if persons be strongly superinduced by the electrical atmosphere of a cloud, they may, under circumstances similar to those explained in that treatise, receive a very strong shock, be knocked down, or be even killed, at the instant that the cloud discharges, with an explosion, its electricity, whether the lightning falls near the very place where those persons are, or at a very considerable distance from that place, or whether the cloud be positively or negatively electrified."

And I further stated that, "whether the distance between the person so circumstanced, and the place where the lightning falls, be fifty or one hundred yards, or one mile, or two miles, or three miles, or more, the truth of the general proposition there laid down would not be anywise affected." I have also explained in that treatise how a still more singular effect might be produced, namely, how "an explosion, which happens in one place, may cause in a

second place, at a very considerable distance from the first place, a sudden returning stroke, which may knock down, or even kill, persons and animals at that second place; at the same time that other persons, or other animals, situated in a third place, that is even immediately between the first place where the lightning falls, and the second place, just mentioned, where the shock of the returning stroke happens, shall receive no detriment whatever."

But, before speaking of the accident of Lauder, which appears to have been occasioned by a returning stroke, proceeding from an assemblage of clouds, I will say a few words on one or two other facts, mentioned in Mr. Brydone's account. Mr. Brydone informs us, that "the shepherd belonging to the farm of Lennel-hill was in a neighbouring field, when he observed a lamb, only a few yards from him, drop down, though the lightning and claps of thunder were then at a great distance from him. He ran up immediately, but found the lamb quite dead; nor did he perceive the least convulsive motion, or symptom of life remaining, though the moment before it appeared to be in perfect health." This effect is so precisely similar to those explained in my Principles of Electricity, that it is quite unnecessary to enlarge on it. I shall only observe, that such an electrical returning stroke as that by which the lamb was destroyed, namely, a returning stroke which happens at a place where there is neither lightning nor thunder near, belongs to the most simple class of returning strokes; and that it may be produced by the sudden removal of the elastic electrical pressure of the electrical atmosphere of a single main cloud, as well as by that of an assemblage of clouds. It appears by Mr. Brydone's account, that the shepherd, who saw the lamb fall, was near enough to it to feel, in a small degree, the electrical returning stroke at the same time that the lamb dropped down.

Mr. Brydone further relates, that "a woman making hay near the banks of the river fell suddenly to the ground; and called out to her companions, that she had received a violent blow on the foot, and could not imagine from whence it came." This blow was, unquestionably, the electrical returning stroke. When a person, walking or standing out of doors, is knocked down or killed by the returning stroke, the electrical fire must rush in, or rush out, as the case may be, through that person's feet, and through them only;

which would not be the case, were the person to be knocked down or killed by any main stroke of explosion, either positive or negative.

Lord S. then proceeds to explain, from the returning stroke, described in his Principles of Electricity, how the chief effects mentioned in Mr. Brydone's account may probably have been produced, viz. the death of the man and horses, with the dispersion of parts of the cart, and the marks on the wheels, &c.

[*Id.* 1787.

13. *Curious case of Heckingham Poor-house being set on fire by Lightning, though guarded by Conductors.*

By Dr. Blagden, and Mr. Nairne.

The first communication is a letter to the president of the R. S. from the principal officers of the Board of Ordnance, dated Dec. 22, 1781, as follows:

Sir,—Having received information that, last summer, a stroke of lightning set fire to the poor-house at Heckingham, near Norwich, notwithstanding it was armed with eight pointed conductors, we request you will communicate to us such particulars relating to that fact as may have come to your knowledge.

(Signed) Amherst; C. Frederick; H. Starchey; J. Kenrick.

Sir Joseph Banks, Bart.
President of the Royal Society.

It does not appear that any particulars relating to that fact had come to the president's knowledge. However, the council of the R. S. appointed a committee of their members to inquire into the particulars, as appears by the following extracts.

Extracts from the Minutes of the Council of the Royal Society.

Jan. 10, 1782.—The president laid before the council a letter to him from the Board of Ordnance, acquainting him, that the poor-house at Heckingham, near Norwich, had been struck by lightning, notwithstanding it was armed with eight pointed conductors; and requesting him to communicate to them such particulars relating to that fact as may have come to his knowledge.—Resolved,

That Dr. Blagden and Mr. Nairne be requested to repair to Heckingham, and examine into the circumstances of the accident, and report thereon to the council: that they engage a draughtsman to take such drawings as may be requisite; and that the necessary expenses be defrayed by the Society.

Feb. 7, 1782.—Dr. Blagden read to the council his and Mr. Nairne's report of the survey made by them of the poor-house at Heckingham, in Norfolk, in consequence of their appointment by a former council. The said report was ordered to be read to the Society on Thursday the 14th instant. And the president was requested to transmit it immediately afterwards to the Board of Ordnance; and to desire that they would return the drawings as soon as they should have taken copies of them, or made such other use of them as they might think necessary.

Report of the Committee.—Read February 14, 1782.—To the President and Council of the Royal Society.—Gentlemen, pursuant to your resolution, appointing us a committee to examine the House of Industry, at Heckingham, in Norfolk, which had been struck by lightning, though it was armed with conductors, we arrived there on the 21st of January. Seven months had then elapsed since the accident, yet we had the satisfaction to learn, that no material changes had been made in the conductors or the building in that period; some laths that had been burnt, some bricks and pantiles which had been damaged or thrown down were replaced; but we found means to procure distinct information of those repairs from the workmen who had been employed to execute them. In order to communicate a clear idea of the accident, it will be necessary to premise a general account of the building; then to represent the manner in which the conductors were applied; and, lastly, to describe the stroke of lightning, with its effects.

The general form of the building is that of the Roman letter H, consisting of a centre range and two flanks. It stands on a gentle rising, which can by no means be termed a hill, with its front facing S. 9° W. To the western side of the west flank, and eastern side of the east flank, some lower buildings are annexed, serving as offices of different kinds; and there are two courts, one before and the other behind the house, with some small gardens

and yards on each of the flanks, in all of which stand various detached offices.

A very minute description is then given of all the parts of the building of the poor-house, with various low detached and attached offices, as lean-tos, stables, yards, privies, pig-houses, &c. &c. the whole illustrated by drawings of plans and elevations in six engraved plates, which may well be spared on this occasion.

To all the eight chimnies of the building they found iron rods affixed, reaching between four and five feet above the top of the chimney, pointed at the upper end, and tapering about ten inches to that point. Each rod or bar was nearly square, measuring, on a mean, about half an inch one way, and $\frac{4}{10}$ of an inch the other, with the angles just rounded off. These conductors were continued down the building by a succession of similar bars of iron, in general from six to eight feet long, joined to each other by two hooks and nuts; that is, the corresponding ends of each bar being formed into a hook bent at right angles, the hook of the uppermost went into a hole of the lowermost, where it was fastened with a nut, and the hook of the lowermost went into a similar hole of the bar above, where it was fixed in the same manner; the length of each of these joints, from nut to nut, was about two inches. Though there were eight of these conductors reaching above the chimnies, yet they had only four terminations below. For the conductors to the two chimnies, called D and E, being continued toward each other along the roof, united in the valley over the lead gutter there, and from that point only one conductor was continued down the valley toward the ground. In like manner the two conductors from the chimnies A and C united in the valley of the roof between them, and were carried down toward the ground as a single rod. All the three conductors from the chimnies F, G, and H, successively joined together, and only a single rod was continued from them down the lower part of the building. Lastly, the conductor from the chimney B went down all the way, without having formed a junction with any other.

The conductors, in their passage down the building, being thus reduced to four, the gentlemen next show their four terminations; which it hence appears were far from being so proper or fit as they ought to have been, being carried but a few inches below the sur-

face of the ground, and dry; instead of being continued to many feet in depth, and ending in water, or very moist earth, as is generally directed in such cases, to render the conductors safe and effectual. The gentlemen, after a minute and careful examination and measurement of all the parts of the building, give a very clear and ample description of them, in their report to the Society; but which may well be omitted, being particulars of very little consequence, and the case itself unimportant. One hip of the extreme corner of the building, at the greatest distance from the conductors, was struck and set on fire by a very loud explosion of lightning; but the fire was quickly extinguished, and little or no damage was sustained. The gentlemen then conclude their report as follows:

Such are the facts we were able to collect from an assiduous examination of the poor-house at Heckingham, and of those witnesses in the neighbourhood who knew any thing of the accident. We have stated the appearances as they presented themselves to us, with all the minuteness that could be preserved without too much crowding the narrative, and independently of any opinions. Whether the earth or the clouds were positive at the time; whether the top or bottom of the hip was first affected by the stroke; whether all the lightning took its course through the hip, or part went that way, and part through the conductors; and how far the conductors were properly constructed, or adequately terminated, are questions which will naturally suggest themselves to your consideration.

(Signed) C. Blagden and Edward Nairne.

[*Id.* 1782.

14. *Effects of Lightning on various Ships in the East-Indies.*

By Mr. Robert Veicht.

August 1st, 1750. Lat. 1° 56′ N. Malacca bearing about N. E. After some clear serene weather, a thunder-cloud arose, and soon increased very fast. The whole heavens were covered with it, and the flashes of lightning happened at times on different sides of the ship, which had all the sails furled, before it came upon her. The wind, which reached the ship before the thunder,

brought with it a violent and heavy rain, which sufficiently soaked the ship and every thing about her. The ship was all this time, which was in about half an hour after its first appearance above the western horizon, in the midst of repeated flashes of lightning, which were just upon the ship by her trembling and shaking on every explosion, and the flash and clap coming in the same instant, the officers and people were apprehensive of damage to the mast.

$2\frac{1}{2}$ A. M. At this time a clap burst, as was judged by the report, about midway between the head of the mast and the body of the ship, or it might be higher, and in descending might cause that appearance, and just over it. This made the ship tremble and shake as if she was going to burst in pieces, and great pieces and splinters of the mast fell on different places of the ship; but it was so very dark we could not see from which of the masts they were forced. Immediately after this first came a second, which burst just above, and on the quarter-deck of the ship, which by the report was as great, and being close on the deck was more terrifying than the former.

At day-light we found that the foremast and mizenmast had escaped, and the mainmast had suffered as follows: All the main-top-gallantmast, from the rigging at the top of it, to the cap at the head of the main-topmast, was entirely carried away, part falling overboard, and part into the ship in different places. The main-topmast had great pieces carried from it, from the hunes down to the cap, at the head of the mainmast, so that it could but just stand, being hardly strong enough to bear its own weight, and that of its rigging. The mainmast being composed of three pieces, towards the top of it, those of the sides being of oak, called the cheeks, were not hurt; but the middlemost part, being of fir, was shivered in several places, and pieces were carried out of it six or seven inches in diameter, and from ten to twelve feet long, and this in a circular descending manner, from the parrel of the main-yard down to the upper deck of the ship, the pieces being taken out crooked, or circular, or straight, according as the grain of the wood ran.

No part of the top-gallantmast, or topmast, that was covered with the lamp-black, was touched with the thunder, the greasy part only being carried away. The head of the top-gallantmast, from the rigging upwards to the spindle, was entire, as was also

its heel, for the lightning did not touch the heel, but missed the whole both of top-gallantmast and topmast, that lay between the cap and upper end of the greasy part of the mast. Of the topmast great pieces were carried out, of many feet in length, and nine or ten inches in thickness, and this on different sides of the mast, for the whole length of the greasy part. From the top of the mainmast to the upper end of that which is covered with turpentine, there was no damage; but thence downwards, the cheeks were started off from the middle part, and pieces taken out winding aslant down the mast, and out of the fir part many feet in length, and six and seven inches deep, and near the upper deck a piece as large as the body of a man, and eleven or twelve feet in length.

Neither the yards nor any part of the rigging were hurt; for though the middle part of the top-gallantmast, which was eighteen feet long, and nine inches in diameter, was entirely burst to pieces, and carried away; yet the rigging which surrounded the upper part was neither burnt, scorched, nor broken. Neither did it touch the caps on the mast heads, nor the top, or round the scaffolding on the mast, which in this ship was eighteen feet broad; and these, as well as the yards, were covered with tar and lamp black, and made of three inch deal.

At the time of the first clap there might be more than sixty men upon deck, and some of them very near the mast at the very time of the clap. Some of these were stunned and beaten down; and in their arms, where they thought themselves hurt, they had a numbness, which continued some time, but not any of them otherwise hurt. Luckily before the second the men who were on the quarter-deck, in number about twenty, had time to retire under the awning, which is a projection of the deck of the cabin, to shelter from the sun or rain; so all escaped unhurt, though sufficiently frighted. And indeed the second flash was most terrible, as it was an explosion like a great number of balls, which went off after each other, cracking like shells, which continued for the space of half a minute; and from which there was no retiring, as the door of the cabin was shut; and they might have set the ship on fire, but for the great rain which had fallen immediately before this.

Anno 1746, a Dutch ship, lying in the road of Batavia, having

taken leave of the governor, was ready to depart for Bengal. The afternoon was calm, and towards evening they had loosed their sails, and lay ready to take up their anchor on the coming off of the wind from the land, which is common every night. A black cloud was gathering over the hills, and the wind brought it towards the ship: by the time the cloud and the wind reached the ship, a clap of thunder burst from it, just over the ship, and set fire to the main-topsail, which being very dry, burnt with great fury; and this set fire to the rigging and mast. They immediately attempted to cut away the mast, but were hindered by the falling of the rigging, which was burnt, from the head of the mast. By degrees the fire communicated to the other masts, and obliged the people to desert the ship; and afterwards it took hold of the body of the ship, and burning down to the powder, the upper part of the hull blew up, and the bottom part sunk in the place where she was at anchor.

Anno 1741, Bencoolen road, on the S. W. side of the island of Sumatra, lat. 4° 0′ south. There lay here two ships, one an European, the other a country trading ship, both belonging to the East India Company. Here, as well as in the straight of Malacca, you have periodical winds, which blow for six months of the year from the same quarter of the horizon, and the other six months from the opposite quarter; and it is observable, that these thunder showers and squalls of wind usually come contrary to these stated winds, which are calmed during the thunder, but return to their constant quarter as soon as the thunder and rain are past. In the above year 1741, in June, the weather was very hot and sultry, and the constant wind but very faint. The wind came after this from the land, and almost opposite to the usual point a very faint air; and the thunder was frequent and close to the ships, which lay near each other, but the fog and rain prevented their seeing each other; they often trembled and shook by the explosion of the thunder. One of these claps burst on the country ship, which by this time had her topmasts struck; that is, lowered down along the lower masts. This clap carried away and burst to pieces all the part of the lower mast from where the yard is carried aloft to within six or seven feet of the upper deck. The mast was woolded with ropes of $2\frac{1}{2}$ size in different places, which were burst asunder at every turn of it; and the mast all shivered into small splinters,

and mostly carried overboard. Here also the mainmast was made of fir, and the part which was split and shivered to pieces, was the part usually coated with turpentine, mixed as beforesaid with tallow or oil: and the main topmast, which was made of a wood of the country called teak, and is of a texture like oak, but stronger, was untouched, notwithstanding it lay parallel and touched the mast for the whole length of the part carried away.

[*Id.* 1764.

15. *Effects of lightning on a Hulk at Plymouth.*

By John Huxham, M. D.

Sunday, December 15, 1754, twenty-five minutes after one P. M. a vast body of lightning fell on the great hulk at Plymouth-dock, which serves to hoist in and fix the masts of the men of war. It burst out about a mile or two to the westward of the hulk, and rushed with incredible velocity towards it. The piece of the Derrick cut out was at least eighteen inches diameter, and about fifteen or sixteen feet long: this particular piece was in three or four places begirt with iron hoops, about two inches broad, and half an inch thick, which were completely cut in two by the lightning, as if done by the nicest hand and instrument. The lightning was immediately succeeded by a dreadful peal of thunder, and that by the most violent shower of hail, which fell only in and about this town, for a mile or two; there was very little of it at the dock, though only two miles distant. The hail-stones were as large as small nutmegs, all very nearly of the same size and shape. They measured, immediately after they fell, near two inches round. [*Id.* 1755.

16. *Thunder-clap, with an extraordinary fire-ball, bursting at sea.*

By Mr. Chalmers.

Nov. 4, 1749, in the latitude of 42° 48′, longitude 9° 3′, the Lizard then bore N. 41° 5′ about the distance of 569 miles, as Mr. C. was taking an observation on the quarter-deck, about ten minutes before 12 o'clock, one of the quarter-masters desired he

would look to windward, which he did, and observed a large ball of blue fire rolling on the surface of the water, at about three miles distance from them. It came down upon them so fast, that before they could raise the main tack, they observed the ball to rise almost perpendicular, and not above forty or fifty yards from the main chains: it went off with an explosion as if hundreds of cannon had been fired at once; and left so great a smell of brimstone, that the ship seemed to be nothing but sulphur. After the noise was over, which did not last longer than half a second, they found the main-topmast shattered into above a hundred pieces, and the mainmast rent quite down to the heel. There were some of the spikes, that nailed the fish of the mainmast, drawn with such force out of the mast, that they stuck in the main deck so fast, that the carpenter was obliged to take an iron crow to get them out: five men were knocked down, and one of them greatly burnt by the explosion. They thought that when the ball, which appeared to be of the size of a large millstone, rose, it took the middle of the main-topmast, as the head of the mast above the hounds was not splintered. The ball came down from the N. E. and went to the S. W. [*Id.* 1750.

17. *Singular effect of thunder and lightning on sea-compasses.*

In a letter from Dublin.

Mr. Haward, a very creditable person, tells me, that being once master of a ship in a voyage to Barbadoes, in company with another commanded by one Grafton, of New-England, in the latitude of Bermudas, they were suddenly alarmed with a terrible clap of thunder, which broke Mr. Grafton's foremast, tore his sails, and damaged his rigging. But that after the noise and confusion were past, Mr. Hayward, to whom the thunder had been more favourable, was however no less surprised to see his companion's ship steer directly homeward again. At first he thought that they had mistaken their course, and that they would soon perceive their error; but seeing them persist in it, and being by this time almost out of call, he tacked and stood after them; and as soon as he got near enough to be well understood, asked where they were going; but by their answer, which imported that they had no other design than the prosecution of their former intended

voyage, and by the sequel of their discourse, it at last appeared that Mr. Grafton did indeed steer by the right point of his compass, but that the card was turned round, the north and south points having changed positions; and though with his finger he brought the fleur-de-lys to point directly north, it would immediately, as soon as at liberty, return to this new unusual posture; and, on examination, he found every compass in the ship altered in the same manner; which strange and sudden accident he could impute to nothing else but the operation of the lightning or thunder just mentioned. He adds, that those compasses never, to his knowledge, recovered their right positions again.

[*Id.* 1676.

18. *Another instance of the above, with greater damage to the Vessel.*

By Captain John Waddle.

On January 9, 1748-9, the new ship Dover, bound from New York to London, being then in latitude 47° 30′ north, and longitude 22° 15′ west, from London, met with a very hard storm of wind, attended with thunder and lightning, as usual, most part of the evening, and sundry very large comazants, as they are called, overhead, some of which settled on the spindles of the top-mast heads, which burnt like very large torches; and at 9 P. M. a single loud clap of thunder with lightning struck the ship in a violent manner, which disabled Captain W. and great part of the ship's company in the eyes and limbs; it struck the mainmast about $\frac{2}{3}$ up almost half through, and stove the upper deck, one carling, and quick-work; part of which lightning got in between decks, started off the bulk-head, drove down all the cabins on one side of the steerage, stove the lower deck, and one of the lower deck main lodging-knees. Another part of it went through the starboard side, without any hurt to the ceiling, or inside plank; and started off from the timbers four outside planks, being the wale upwards; one of which planks, being the second from the wale, was broke quite asunder, and let in: in about ten or fifteen minutes time nine feet water in the ship.

It also took the virtue of the loadstone from all the compasses, being four in number, all in good order before, one in a brass and

three in wooden boxes. The hanging compass in the cabin was not quite so much disabled as the rest; they were at first very near reversed, the north to the south; and after a little while rambled about so as to be of no service. The storm lasted five days; they lost the mainmast and mizenmast, and almost all the sails; and arrived at Cowes the 21st of January in a very shattered condition.

[*Phil. Trans.* 1749.

19. *Examination of the preceding Mariner's Compass; and the Explanation of the Cause of its reversed polarity.*

By Gowin Knight, M. B. F. R. S.

On examining the compass struck with lightning, it appeared that the outward case was joined together with pieces of iron wire, sixteen of which were found in the sides of the box, and ten in the bottom. Mr. K. applied a small needle to each of these wires, and immediately perceived that the lightning had made them strongly magnetical; particularly those that joined the sides. All the heads of the wires on one side of the box attracted the north point of the needle and repelled the south; while all the heads on the other side attracted the south and repelled the north; the wires at the bottom attracted the south and repelled the north; but it is not certain whether this polarity was anywise owing to the lightning; since it might be acquired by their continuing long in an erect position.

On examining the card, he found the needle was vigorous enough in performing its vibrations, but that its polarity was inverted; the north point turning contrary to the south. He then tried to take out the card, to examine the state and structure of the needle: but the junctures, every where well secured with putty, become so hard, that he was obliged to use some violence, and at last broke the glass. The needle consisted of two pieces of steel wire, each bent in the middle, so as to make an obtuse angle; and the ends of these wires applied together, forming an acute one, the whole appearing in the shape of a lozenge; in the centre of which was placed a brass cap, on which the card turned. And so far was it from being made with any tolerable degree of exactness, that there was not the least care taken either to bend the wires in the middle, or to fix the cap exactly in the centre of the lozenge.

The pin on which it turned, was made of a slip of plate brass sharpened to a point.

Besides the particulars already communicated to the Society, the captain informed him, that he was obliged to sail above 300 leagues, after this accident happened, without a compass, till he arrived at Cowes in the Isle of Wight; where being provided with one, he placed it in the binnacle, but was much surprised to find that it varied from the direction it stood at when out of the binnacle nearly two points. He removed the binnacle to different parts of the deck, but found that it always made the needle to vary after the same manner when placed in it. He repeated the same experiment lately in the river, with the like success; only that he observed, that the variation of the needle, when placed in the binnacle, was rather less than at first. It was natural to inquire if there was any iron about the binnacle; but the Captain said he had given a strict charge to the maker not to put so much as a single nail in it; and that he firmly believed that there was not the least bit of iron about it.

Being willing to be satisfied of the truth of a circumstance so very extraordinary, the captain was desired to send the binnacle to a house in the city; where, in company with the Captain, Mr. Ellicot, and another gentleman, Mr. K. tried it with a large compass touched by his bars; but finding no sensible variation, they at that time desisted, thinking the fact quite improbable; but having discovered the effect which the lightning had produced on the wires which fastened the sides of the compass box, he was induced to examine the binnacle a second time; which he did with a small compass, and with great care, in every part; and at last, about the middle of the binnacle, he found it to vary very sensibly, but could not discover any nails or iron thereabouts; till turning it up to examine the bottom, he there found three or four large nails, or rather spikes, driven through it to fasten the upright partitions in the middle of the binnacle.

It would not be difficult to explain why any needles, under such circumstances, should be rendered useless by lightning, though the needles themselves had remained unhurt. So many iron wires made strongly magnetical would doubtless have effected it; and three or four large nails in the binnacle, if made magnetical, would alone have been sufficient to have done it. But it has always been noticed that the polarity of the needle was inverted by this acci-

dent; and he further observes, that all needles constructed after this manner are liable to be rendered useless, not only by the lightning's destroying their virtue, but also by its placing it in a particular direction; ex. gr. if the lightning struck the needle in the direction of either of the two parallel sides of the lozenge, it must strike the other two sides very obliquely; by which the first two sides may have their polarity destroyed, and a very strong one given them in the contrary direction; while that of the other sides, if it be inverted, will be very weak; but it is probable that the virtue would be placed obliquely in the direction of the stroke; in either case, these two sides can contribute but very little, if any thing, in directing the card; and if the first two sides only be capable of acting on it, it will point in the direction of those sides, which will produce a variation of about four points.

It may further be observed that a needle would not continue long in this state, but would every day grow more regular; because if the virtue be placed obliquely, it generally turns itself in the direction of any piece of steel that is long and slender; and that may be the reason why this card is now become regular, except that it is inverted.

The wires that join the box seem weaker than when first examined; which makes it very probable that they might be vastly stronger when first struck with the lightning; and the same may be likewise true, in regard to the nails in the binnacle; which may account for the experiments not answering exactly the same as at first.

From what has been said it appears, that this form of needles is very improper, and ought to be changed for that of one straight piece of steel; and then if a needle should be inverted, it might still be used. It also shews the absurdity of permitting iron of any kind about the compass box, or the binnacle. Whoever considers the whole description here given of this compass, will esteem it a most despicable instrument; how then must any one be shocked to hear, that almost all the compasses made use of by our trading vessels are of the same sort; the boxes are all joined with iron wire, and the same degree of inaccuracy observed throughout the whole!

[*Id.* 1749.

SECTION V.

Death of Professor Richman by Lightning, with Observations on the same.

1. Extract of a Letter from John Lining, M. D. of Charlestown, South Carolina, to Charles Pinkney, Esq. London, with his answer to several Queries sent to him concerning his Experiment of Electricity with a Kite*. Dated Charlestown, January 14, 1754.

INCLOSED are answers to the queries sent me concerning the experiment with the kite. Since making that experiment last May, I have not had an opportunity of making any more, having been confined all the summer and autumn with the gout, which perhaps prevented my meeting with the same unhappy fate with Professor Richman of Petersburg. It appears that the professor had a wire, which came down from the iron rod, erected on his house, through the gallery ceiling, to an iron bar, which stood in a glass vessel, filled with water and filings of brass; and that the professor stood so near that iron rod, that his face was within a foot of it. Now if there was no wire that went from that iron rod, or from any part of the wire above it, into the earth, it is no great wonder that the professor was killed. I should be extremely glad to be informed, whether the iron rod on his house, at the time the experiment was made, had any communication, by means of metal, with the earth. For if it had, there is then more danger attending these experiments than I imagined. It is likewise said in the account, that from the electrical needle, which he observed, there was no danger. I am at a loss to know what that electrical needle was, and should be glad to be informed. I know that a magnetic needle placed on a sharp point on the prime conductor, as soon as the conductor is sufficiently electrified, will move round with so great rapidity, that in the dark the electricity, thrown off from both poles of the needle, will appear like a circle of fire.

Answers of Dr. Lining to the Queries sent to him.

Query 1. In what manner, and of what materials, was your

* See on Dr. Franklin's electrical kite, sec. ii. of this chapter.

kite and the string by which you flew it, made? and to what height did it rise above the earth?

Answer. The kite, which I used, was made in the common way; only, instead of paper, I covered it with a silk, called alamode. The line was a common small hempen one of three strands. A silk line, except it had been kept continually wet, would not conduct the electricity; and a wire, besides other inconveniencies, would have been too heavy. I had not any instrument to take the height of the kite; but believe it was at least 250 feet high. It was flown in the day-time.

Query 2.—You say also, "*All* the electrical fluid, or lightning, was drawn from the cloud, and discharged in the air; and a greater degree of serenity succeeded, and no more of the awful noise of thunder, before expected, was heard." Now I should be glad you would inform us, whether the serenity in the air was such, as generally follows, after the clouds in the summer thunder-storms have discharged several loud thunder-claps; and whether any flashes of lightning appeared in the skies, after you had discharged the cloud of its lightning by the kite, as commonly do after a thunder-storm is over in a summer's night? for if there were no appearance of such flashes, then I think your assertion, that *all* the electric fluid, or lightning, was drawn from the cloud, stands fully proved; but if there were such flashes after, I conceive there must have been some of the electrical matter left behind.

Answer.—During the time of my drawing the lightning from the cloud, and for some little time afterward, it rained; by which means the body of the cloud being diminished, a greater degree of serenity necessarily succeeded; and the quantity of lightning extracted from the cloud, or rather its atmosphere, proved sufficient to prevent any thunder in town that afternoon; though there was a great appearance of thunder before the kite was raised. But whether the same serenity succeeded, as frequently happens after a thunder-storm, and whether there were any flashes of lightning seen in the evening, I cannot now recollect. If such flashes had afterwards been seen in the skies, as is common in a summer's evening, especially after a thunder-storm, those might proceed from other clouds, which had passed the town, at too great a distance to be acted on by the kite.

Electrified clouds have an electrical atmosphere, as well as the prime conductor, when it is electrified; and the diameter of that atmosphere, cæteris paribus, will bear some proportion to the size of the cloud. My smallest prime conductor is $2\frac{1}{2}$ inches in diameter; and when it is fully charged, its atmosphere extends to the distance of about three feet from the surface of the conductor. How great then must the extent be of the atmosphere, which surrounds a large cloud fully electrified? It perhaps may extend to many hundreds of feet round the cloud, and may even reach so low as to touch the surface of the earth: and when that is the case, a man, or a rod of metal, placed on a cake of resin on the ground, may be electrified and yield sparks of fire. When a sharp point is presented to that atmosphere, it cannot deprive the cloud of its whole quantity of electricity, except the sharp point be so near, that the cloud may explode upon it; and in that case the cloud must have a communication with the ground, by means of some non-electric body. Suppose an electrified cloud to have an atmosphere, which extends round it to the distance of ninety feet from its surface; and let that atmosphere be divided into three parts, A, B, and C, each thirty feet in diameter: now, if a sharp metalline point erected on a kite, or otherwise, be placed either vertically or horizontally in the most interior part of the atmosphere C, that point will continue to act till a quantity of the lightning is drawn off, equal to the quantity contained in that atmosphere, and no longer. For then the semidiameter of the atmosphere being reduced to 60 feet, every part of it is above, and not in contact with the sharp point, and consequently beyond its sphere of action. But let the sharp point be then advanced into the atmosphere B, and it will act as before, &c.

The truth of this, however contradictory it may be, to the general opinion of the action of sharp points, in drawing off the electricity or lightning*, may be illustrated by the following experiments on the prime conductor. Electrify the prime conductor in a dark room, and draw back the globe to a sufficient distance from the prime conductor, to prevent its being supplied with any more electricity from the globe, while you are taking off the elec-

* Mr. Franklin says, speaking of sharp points, "At whatever distance you see the light, you may draw off the electrical fire," page 2.—Orig.

trical atmosphere with a sharp point. Bring then a sharp point, either vertically or horizontally, or in any other direction, within two feet of the prime conductor; and the point, for some time, will appear luminous. After that light disappears advance the point three or four inches nearer to the conductor, and you will observe the same phenomena as before; and by advancing the point gradually in this manner, as the light on it disappears, the point will be alternately luminous and dark, till you have taken off the whole atmosphere in different laminæ. As the point appears more and more luminous, the nearer that it approaches the prime-conductor, the electrical atmosphere may have different degrees of density, being perhaps denser near the prime-conductor, and rarer at a greater distance from it. If a phial be charged on the prime-conductor, when this experiment is made, the light on the sharp point will be much greater, and continue longer.

Query 3.—Did you make any trial at what distance you could kill an animal, with a discharge of the electrical fluid from the key or the bottle suspended to it?

Answer.—I have not hitherto had an opportunity of making any such experiment with the kite. But as to the first, I apprehend, that no animal could be killed by the discharge of any quantity of electricity accumulated on the key; as the key in that experiment answers the same end as the prime conductor; and, like it, is capable of receiving *only* a certain charge of electricity, except the lightning flows down the line too fast, or the kite be so near the cloud that it may explode, when one standing on the ground approaches the key to draw sparks from it: but such an explosion would probably be fatal to the operator. When a phial is suspended to the key, after it has received its charge, if you let it continue hanging on the key, the surcharge will fly off from the hook of the phial, and the phial, when charged in that manner, will not give a greater shock than if it had been charged in the common way with the globe.

2. Answer to Dr. Lining's Query relative to the Death of Professor Richman.

By Mr. William Watson, F.R.S.

Dr. Lining's letter of the 14th of January, 1754, being communicated to the Royal Society by Charles Pinkney, Esq. that learned body referred it to Mr. Watson, one of their members, in order that the best information, that could be procured on this subject, should be transmitted to Dr. Lining, for whose correspondence the Society had for many years had a very particular attention. Mr. Watson imagined, that it would be agreeable to Dr. Lining, as his abode is so remote from Petersburgh, where the accident happened, to have transmitted to him not only the answer to what he more particularly requests, but also as general an account of every thing relating to so uncommon an accident, as could be procured.

The description of Professor Richman's apparatus, as sent by himself to Professor Heinsius of Leipsic, he called an electrical gnomon. To the construction of this gnomon were necessary a rod of metal, a glass jar, a linen thread, of a foot and a half in length, to one end of which was fastened half a grain of lead, and a quadrant. A rod of metal was placed in the glass vessel which contained filings of metal. The linen thread was fastened to the rod, and, when the apparatus is not electrized, hangs perpendicularly down. The radius of the quadrant, which was divided into degrees, was two lines more than a foot and a half in length. And here must be added an account of the other part of the apparatus, which was to communicate the electricity to the gnomon during a thunder-storm. Through a glass bottle, the bottom of which was perforated, passed an iron rod, which was kept in its place by means of a cork fixed to the mouth of this bottle, through which cork likewise was inserted the iron rod. A tile was removed from the top of the house; and on this opening was placed the bottle, supported by the neighbouring tiles, in such a manner that one end of the iron rod was not only four or five feet above the top of the house; but the other end, which came through the

bottom of the bottle, did no where touch the tiles, or any other part of the house. To this end of the iron rod was fastened an iron chain, which was conducted into the chamber of Professor Richman, on electrics per se, so as no where to touch the building. The entrance to this chamber faced the north; and at the south end of it there was a window, near which stood a table four feet in height. On this the professor placed his electrical gnomon, and connected it with the chain, which was brought under the ceiling of the room over this table, and communicated with the apparatus on the top of the house, by means of a wire which hung from the chain, and was joined there by a little ring, and communicated with the rod. When the iron rod at the top of the house was affected by the thunder, or otherwise suitable condition of the atmosphere, the thread before-mentioned deviated from the perpendicular; as it would also do, if artificially electrized. The Professor always observed a greater ascent of the thread from artificial electricity than by that from the atmosphere. By the former, he had seen it on the quadrant describe an angle of above 55°, but never above 30 by the latter. In the year 1752, August 9, the apparatus acquired so great a degree of electricity from the atmosphere, that from the end of the rod the electrical flashes might be heard at several feet distance. Under these circumstances, if any one touched the apparatus, they felt a sharp stroke in their hand and arm.

Professor Richman sometimes added to this apparatus a glass bottle of water, after the manner of Professor Muschenbroek, adapted to a vessel of metal placed on glass. The wire from the mouth of the bottle of water, during the time of the thunder, he caused to communicate with another wire. From this addition he found the electricity from the atmosphere more vehement than it was without it. This he first observed on May 31, 1753, when the electrical fire exploded with such a force, that it might be heard at the distance of three rooms from the apparatus. On the left hand of the bottle was placed a second electrical gnomon. When this was made use of, the wire of the one metal, and the wire of the other, were connected with a prime conductor from an apparatus for artificial electricity, viz. a glass globe, &c. At the same time also, from the chain was fastened a piece of wire in contact with the vessel. By these means, when the electrical machine was put in motion, both the electrical gnomons

were electrified: but this went off, in a great measure, as soon as the motion of the machine ceased. By this whole apparatus taken together, Professor Richman observed a kind of reciprocation in the effects of electricity; for at first, when the electrical machine was put in motion, both the linen threads arose with the degrees of their respective quadrants. If then the wire of the right gnomon was touched, the right-hand thread collapsed to the rod; but the thread on the left side continued diverging as before the touch. Also, if the wire of the left gnomon was touched, then in its turn the thread at the rod of the right gnomon collapsed, and the thread of the right gnomon ascended again. This reciprocation of the ascending and descending of the thread, might be repeated three or four times without exciting the machine anew.

The ingenious and industrious Professor Richman lost his life on the 6th of August, 1753, as he was observing, with Mr. Sokolow, engraver to the Royal Academy at Petersburgh, the effects of electricity on his gnomon, during a thunder-storm. As soon as his death was publicly known, it was imagined that the lightning was more particularly directed into his room by the means of his before-mentioned apparatus. And when this affair was more inquired into, this opinion appeared to be not ill-founded; for Mr. Sokolow saw that a globe of blue fire, as large as his fist, jumped from the rod of the right gnomon, towards the forehead of Professor Richman, who at that instant was at about a foot distance from the rod, observing the electrical index. This globe of fire, which struck Professor Richman, was attended with a report as loud as that of a pistol. The nearest metal wire was broken in pieces, and the fragments thrown on Mr. Sokolow's clothes, from their heat burnt marks of their dimensions on them. Half of the glass vessel was broken off, and the filings of metal in it were thrown about the room. Hence it is plain, that the force of the lightning was collected on the right rod, which touched the filings of metal in the glass vessel. On examining the effects of lightning in the Professor's chamber, they found the door-case split half through, and the door torn off, and thrown into the chamber. The lightning therefore seems to have continued its course along the chain, conducted under the ceiling of the room; but that it came from the apparatus at the top of the house to the

door, and then into the chamber, does not, as far as can be recollected, appear.

If indeed it could be ascertained, that the lightning, which was the death of Professor Richman, was collected on the apparatus, for this reason, because these bodies, at the instant of the lightning, were capable of attracting and retaining the electricity, it would then be in our power sometimes to divert the effects of lightning. But of this fact, more time and longer experience must acquaint us with the truth.

Hence Mr. Pinkney may acquaint Dr. Lining, that in Mr. Watson's opinion, at the time Professor Richman was killed, his apparatus was perfectly insulated, and had no communication with the earth, by the means of metallic or other substances, readily conducting electricity, and that the great quantity of electricity, with which, from the vastness of the cause, the apparatus was replete, discharging itself through the Professor's body, being the nearest non-electric substance in contact with the floor, and was unfortunately the cause of his death. This, it is presumed, would not have happened, had the chain, or any other part of the apparatus, touched the floor, by which the electricity would have been readily communicated to the earth.

Since the reading of the above to the Royal Society, a treatise in Latin, entitled, Oratio de Meteoris vi Electrica Ortis, by Mr. Lomonosow, of the Royal Academy of Sciences at Petersburg, has been transmitted to the Society. By this, among many other curious facts, we have been informed of certain particulars in regard to the death of Professor Richman; of which the following may not be improper to be inserted here.

Mr. Lomonosow observes, that with regard to the sudden death of the gentleman before-mentioned, the accounts, communicated to the public, contained some circumstances not fairly stated, and others of some importance were entirely omitted. With regard to the first, it is incontestably true, that the window, in the room where Professor Richman was, had continued shut, that the wind might have no effect on his electrometer; but that the window in the next room was open, and the door between these two rooms was half open; so that the draught of air might justly be suspected to have followed the direction of the iron conductor of the Professor's apparatus; that his conductor came

from the top of the house, and was continued as far as necessary. Secondly, That his conductor was not placed far from that door-case, part of which was torn off. Thirdly, That at this time no use was made of the Leyden bottle, mentioned in the preceding account; but the iron was inserted into a glass stand, to prevent the dissipation of the electrical power, and that the gnomon should show its real strength.

With regard to the second, there has as yet been no mention, that Professor Richman, at the time of his death, had seventy rubles (a silver coin) in his left coat-pocket, which by this accident were not in the least altered. Secondly, That his clock, which stood in the corner of the next room, between the open window and the door, was stopped; and that the ashes from the hearth were thrown about the room. Thirdly, That many persons without doors declared their having actually seen the lightning shoot from the cloud to the Professor's apparatus at the top of his house. In the Phil. Trans. is given a view of the chamber, where the Professor was struck by the lightning: who stood with his head projecting towards his electrometer; near stood Mr. Sokolow the engraver; from the door a piece was torn off, and carried forward; part of the door-case was also rent.

In this treatise Mr. Lomonosow, among other phænomena of electricity, takes notice, that he once saw, in a storm of thunder and lightning, brushes of electrical fire, with a hissing noise, communicate between the iron rod of his apparatus and the side of his window; and that these were three feet in length, and a foot in breadth. Effects like these no one but himself has had the opportunity of observing.

[*Phil. Trans.* 1754.

CHAP. XLIV.

ON MAGNETISM.

SECTION I.

General Remarks on the Theory and Parts of Magnetism.

THE theory of magnetism bears a very strong resemblance to that of electricity, and it must therefore be placed near it in a system of natural philosophy. We have seen the electric fluid not only exerting attractions and repulsions, and causing a peculiar distribution of neighbouring portions of a fluid similar to itself, but also excited in one body, and transferred to another, in such a manner as to be perceptible to the senses, or at least to cause sensible effects, in its passage. The attraction and repulsion, and the peculiar distribution of the neighbouring fluid, are found in the phenomena of magnetism; but we do not perceive that there is ever any actual excitation, or any perceptible transfer of the magnetic fluid from one body to another distinct body; and it has also this striking peculiarity, that metallic iron is very nearly, if not absolutely, the only substance capable of exhibiting any indications of its presence or activity.

For explaining the phenomena of magnetism, we suppose the particles of a peculiar fluid to repel each other, and to attract the particles of metallic iron with equal force, diminishing as the square of the distance increases; and the particles of such iron must also be imagined to repel each other, in a similar manner. Iron and steel, when soft, are conductors of the magnetic fluid, and become less and less pervious to it as their hardness increases. The ground work of this theory is due to Mr. Aepinus, but the forces have been more particularly investigated by Coulomb and others. There are the same objections to these hypotheses as to those which constitute the theory of electricity, if considered as original and fundamental properties of matter: and it is additionally difficult to

imagine, why iron, and iron only, whether apparently magnetic or not, should repel similar particles of iron with a peculiar force, which happens to be precisely a balance to the attraction of the magnetic fluid for iron. This is obviously improbable; but the hypotheses are still of great utility in assisting us to generalize, and to retain in memory, a number of particular facts which would otherwise be insulated. The doctrine of the circulation of streams of the magnetic fluid has been justly and universally abandoned, and some other theories, much more ingenious and more probable, for instance that of Mr. Prévost, appears to be too complicated, and too little supported by facts, to require much of our attention.

The distinction between conductors and non-conductors is, with respect to the electric fluid, irregular and intricate; but in magnetism, the softness or hardness of the iron or steel constitutes the only difference. Heat, as softening iron, must consequently render it a conductor; even the heat of boiling water affects it in a certain degree, although it can scarcely be supposed to alter its temper; but the effect of a moderate heat is not so considerable in magnetism as in electricity. A strong degree of heat appears, from the experiments of Gilbert, and of Mr. Cavallo, to destroy completely all magnetic action.

It is perfectly certain that magnetic effects are produced by quantities of iron incapable of being detected either by their weight or by any chemical tests. Mr. Cavallo found that a few particles of steel, adhering to a hone, on which the point of a needle was slightly rubbed, imparted to it magnetic properties; and Mr. Coulomb has observed that there are scarcely any bodies in nature which do not exhibit some marks of being subjected to the influence of magnetism, although its force is always proportional to the quantity of iron which they contain, as far as that quantity can be ascertained; a single grain being sufficient to make 20 pounds of another metal sensibly magnetic. A combination with a large proportion of oxygen deprives iron of the whole or the greater part of its magnetic properties; finery cinder is still considerably magnetic, but the more perfect oxides and the salts of iron only in a slight degree; it is also said that antimony renders iron incapable of being attracted by the magnet. Nickel, when freed from arsenic and from cobalt, is decidedly magnetic, and the more so as it contains less iron. Some of the older chemists supposed nickel to

be a compound metal containing iron, and we may still venture to assume this opinion as a magnetical hypothesis. There is indeed no way of demonstrating that it is impossible for two substances to be so united as to be incapable of separation by the art of the chemist: had nickel been as dense as platina, or as light as cork, we could not have supposed that it contained any considerable quantity of iron, but in fact the specific gravity of these metals is very nearly the same, and nickel is never found in nature but in the neighbourhood of iron; we may therefore suspect, with some reason, that the hypothesis of the existence of iron in nickel may be even chemically true. The aurora borealis is certainly in some measure a magnetical phenomenon, and if iron were the only substance capable of exhibiting magnetic effects, it would follow that some ferruginous particles must exist in the upper regions of the atmosphere. The light usually attending this magnetical meteor may possibly be derived from electricity, which may be the immediate cause of a change of the distribution of the magnetic fluid, contained in the ferruginous vapours, that are imagined to float in the air.

We are still less capable of distinguishing with certainty in magnetism, than in electricity, a positive from a negative state, or a real redundancy of the fluid from a deficiency. The north pole of a magnet may be considered as the part in which the magnetic fluid is either redundant or deficient, provided that the south pole be understood in a contrary sense: thus, if the north pole of a magnet be supposed to be positively charged, the south pole must be imagined to be negative; and in hard iron or steel these poles may be considered as unchangeable.

A north pole, therefore, always repels a north pole, and attracts a south pole. And in a neutral piece of soft iron, near to the north pole of a magnet, the fluid becomes so distributed by induction, as to form a temporary south pole next to the magnet, and the whole piece is of course attracted, from the greater proximity of the attracting pole. If the bar is sufficiently soft, and not too long, the remoter end becomes a north pole, and the whole bar a perfect temporary magnet. But when the bar is of hard steel, the state of induction is imperfect, from the resistance opposed to the motion of the fluid; hence the attraction is less powerful, and an opposite pole is formed, at a certain distance, within the bar; and

beyond this another pole, similar to the first; the alternation being sometimes repeated more than once. The distribution of the fluid within the magnet is also affected by the neighbourhood of a piece of soft iron, the north pole becoming more powerful by the vicinity of the new south pole, and the south pole being consequently strengthened in a certain degree; so that the attractive power of the whole magnet is increased by the proximity of the iron. A weak magnet is capable of receiving a temporary induction of a contrary magnetism from the action of a more powerful one, its north pole becoming a south pole on the approach of a stronger north pole; but the original south pole still retains its situation at the opposite end, and restores the magnet nearly to its original condition, after the removal of the disturbing cause.

The polarity of magnets, or their disposition to assume a certain direction, is of still greater importance than their attractive power. If a small magnet, or simply a soft wire, be poised on a centre, it will arrange itself in such a direction, as will produce an equilibrium of the attractions and repulsions of the poles of a larger magnet; being a tangent to a certain oval figure, passing through those poles, of which the properties have been calculated by various mathematicians. This polarity may easily be imitated by electricity; a suspended wire being brought near to the ends of a positive and negative conductor, which are placed parallel to each other, as in Nairne's electrical machine, its position is perfectly similar to that of a needle attracted by a magnet, of which those conductors represent the poles.

The same effect is observable in iron filings placed near a magnet, and they adhere to each other in curved lines, by virtue of their induced magnetism, the north pole of each particle being attached to the south pole of the particle next it. This arrangement may be seen by placing the filings either on clean mercury, or on any surface that can be agitated; and it may be imitated by strewing powder on a plate of glass, supported by two balls, which are contrarily electrified.

The polarity of a needle may often be observed when it exhibits no sensible attraction or repulsion as a whole; and this may easily be understood by considering that when one end of the needle is repelled from a given point, and the other is attracted towards it, the two forces, if equal, will tend to turn it round its centre, but

will wholly destroy each other's effects with respect to any progressive motion of the whole needle. Thus, when the end of a magnet is placed under a surface on which iron filings are spread, and the surface is shaken, so as to leave the particles for a moment in the air, they are not drawn sensibly towards the magnet, but their ends, which are nearest to the point over the magnet, are turned a little downwards, so that they strike the paper further and further from the magnet, and then fall outwards, as if they were repelled by it.

The magnets, which we have hitherto considered, are such as have a simple and well determined form; but the great compound magnet, which directs the mariner's compass, and which appears to consist principally of the metallic and slightly oxidated iron, contained in the internal parts of the earth, is probably of a far more intricate structure, and we can only judge of its nature from the various phænomena derived from its influence.

The accumulation and the deficiency of the magnetic fluid, which determine the place of the poles of this magnet, are probably in fact considerably diffused, but they may generally be imagined, without much error in the result, to centre in two points, one of them nearer to the north pole of the earth, the other to the south pole. In consequence of their attractions and repulsions, a needle whether previously magnetic or not, assumes always, if freely poised, the direction necessary for its equilibrium; which, in various parts of the globe, is variously inclined to the meridian and to the horizon. Hence arises the use of the compass in navigation and in surveying: a needle, which is poised with a liberty of horizontal motion, assuming the direction of the magnetic meridian, which for a certain time remains almost invariable for the same place; and a similar property is also observable in the dipping needle which is moveable only in a vertical plane; for when this plane is placed in the magnetic meridian, the needle acquires an inclination to the horizon, which varies according to the situation of the place with respect to the magnetic poles.

The natural polarity of the needle may be in some measure illustrated by inclosing an artificial magnet in a globe; the direction of a small needle, suspended over any part of its surface, being determined by the position of the poles of the magnet, in

the same manner as the direction of the compass is determined by the magnetical poles of the earth, although with much more regularity. In either case the whole needle is scarcely more or less attracted towards the globe than if the influence of magnetism were removed; except when the small needle is placed very near to one of the poles of the artificial magnet; or, on the other hand, when the dipping needle is employed in the neighbourhood of some strata of ferruginous substances, which, in particular parts of the earth, interfere materially with the more general effects, and alter the direction of the magnetic meridian.

A bar of soft iron, placed in the situation of the dipping needle, acquires from the earth, by induction, a temporary state of magnetism, which may be reversed at pleasure by reversing its direction; but bars of iron, which have remained long in or near this direction, assume a permanent polarity; for iron, even when it has been at first quite soft, becomes in time a little harder. A natural magnet is not more than a heavy iron ore, which, in the course of ages, has acquired a strong polarity from the great primitive magnet. It must have lain in some degree detached, and must possess but little conducting power, in order to have received and to retain its magnetism.

We cannot, from any assumed situation of two or more magnetic poles, calculate the true position of the needle for all places; and even in the same place, its direction is observed to change in the course of years, according to a law which has never yet been generally determined, although the variation which has been observed, at any one place, since the discovery of the compass, may perhaps be comprehended in some very intricate expressions; but the less dependence can be placed on any calculations of this kind, as there is reason to think that the change depends rather on chemical than on physical causes. Dr. Halley indeed conjectured that the earth contained a nucleus, or separate sphere, revolving freely within it, or rather floating in a fluid contained in the intermediate space, and causing the variation of the magnetic meridian; and others have attributed the effect to the motions of the celestial bodies: but in either case the changes produced would have been much more regular and universal than those which have been actually observed. Temporary changes of the terrestrial magnetism have certainly been sometimes occasioned by

other causes; such causes are, therefore, most likely to be concerned in the more permanent effects. Thus the irruption of Mount Hecla was found to derange the position of the needle considerably; the aurora borealis has been observed to cause its north pole to move 6 or 7 degrees to the westward of its usual position; and a still more remarkable change occurs continually in the diurnal variation. In these climates the north pole of the needle moves slowly westwards from about eight in the morning till two, and in the evening returns again; a change which has with great probability been attributed to the temporary elevation of the temperature of the earth, eastwards of the place of observation, where the sun's action takes place at an earlier hour in the morning, and to the diminution of the magnetic attraction in consequence of the heat thus communicated. In winter this variation amounts to about seven minutes, in summer to thirteen or fourteen.

Important as the use of the compass is at present to navigation, it would be still more valuable if its declination from the true meridian were constant for the same place, or even if it varied according to any discoverable law; since it would afford a ready mode of determining the longitude of a place by a comparison of an astronomical observation of its latitude with another of the magnitude of the declination. And in some cases it may even now be applied to this purpose, where we have a collection of late and numerous observations. Such observations have from time to time been arranged in charts, furnished with lines indicating the magnitude of the declination or variation at the places through which they pass, beginning from the line of no variation, and proceeding on the opposite sides of this line to show the magnitude of the variation east or west. It is obvious that the intersection of a given parallel of latitude, with the lines showing the magnitude of the variation, will indicate the precise situation of the place at which the observations have been made.

The line of no variation passed in 1657 through London, and in 1666 through Paris: its northern extremity appears to have moved continually eastwards, and its southern parts westward; and it now passes through the middle of Asia. The opposite portion seems to have moved more uniformly westwards: it now runs from North America to the middle of the South Atlantic. On

the European side of these lines, the declination is westerly; on the South American side, it is easterly. The variation in London has been for several years a little more than 24°. In the West Indies it changes but slowly; for instance it was 5° near the island of Barbadoes, from 1700 to 1756.

The dip of the north pole of the needle in the neighbourhood of London is 72°. Hence the lower end of a bar standing upright, as a poker, or a lamp iron, becomes always a north pole, and the temporary south pole of a piece of soft iron being uppermost, it is somewhat more strongly attracted by the north pole of a magnet placed over it, than by its south pole; the distribution of the fluid in the magnet itself being also a little more favourable to the attraction, while its north pole is downwards. It is obvious that the magnetism of the northern magnetic pole of the earth must resemble that of the south pole of a magnet, since it attracts the north pole; so that if we considered the nature of the distribution of the fluid rather than its situation in the earth, we should call it a south pole. Although it is impossible to find any places for two, or even for a greater number of magnetic poles, which will correctly explain the direction of the needle in every part of the earth's surface, yet the dip may be determined with tolerable accuracy, from the supposition of a small magnet placed at the centre of the earth, and directed towards a point in Baffin's Bay, about 75° north latitude, and 70° longitude west of London; and the variation of the dip is so inconsiderable, that a very slow change of the position of this supposed magnet would probably be sufficient to produce it; but the operation of such a magnet, according to the general laws of the forces concerned, could not possibly account for the very irregular disposition of the curves indicating the degree of variation or declination; a general idea of these might perhaps be obtained from the supposition of two magnetic poles situated in a line considerably distant from the centre of the earth; but this hypothesis is by no means sufficiently accurate to allow us to place any dependence on it.

The art of making magnets consists in a proper application of the attractions and repulsions of the magnetic fluid, by means of the different kinds of iron and steel, to the production and preservation of such a distribution of the fluid in a magnet, as is the best fitted to the exhibition of its peculiar properties.

We may begin with any bar of iron that has long stood in a vertical position; but it is more common to employ an artificial magnet of greater strength. When one pole of such a magnet touches the end of a bar of hard iron or steel, that end assumes in some degree the opposite character, and the opposite end the same character: but in drawing the pole along the bar, the first end becomes neutral, and afterwards has the opposite polarity; while the second end has its force at first a little increased, then becomes neutral, and afterwards is opposite to what it first was. When the operation is repeated, the effect is at first in some measure destroyed, and it is difficult to understand why the repetition adds materially to the inequality of the distribution of the fluid; but the fact is certain, and the strength of the new magnet is for some time increased at each stroke, until it has acquired all that it is capable of receiving. Several magnets, made in this manner, may be placed side by side, and each of them being nearly equal in strength to the first, the whole collection will produce together a much stronger effect; and in this manner we may obtain from a weak magnet others continually stronger, until we arrive at the greatest degree of polarity of which the metal is capable. It is, however, more usual to employ the process called the double touch: placing two magnets, with their opposite poles near to each other, or the opposite poles of a single magnet, bent into the form of a horse-shoe, in contact with the middle of the bar: the opposite actions of these two poles then conspire in their effort to displace the magnetic fluid, and the magnets having been drawn backwards and forwards repeatedly, an equal number of times to and from each end of the bar, with a considerable pressure, they are at last withdrawn in the middle, in order to keep the poles at equal distances.

Iron filings, or the scoriæ from a smith's forge, when finely levigated, and formed into a paste with linseed oil, are also capable of being made collectively magnetic. A bar of steel, placed red hot between two magnets, and suddenly quenched by cold water, becomes in some degree magnetic, but not so powerfully as it may be rendered by other means. For preserving magnets, it is usual to place their poles in contact with the opposite poles of other magnets, or with pieces of soft iron, which, in consequence of their own induced magnetism, tend to favour the accumulation of

the magnetic power in a greater quantity than the metal can retain after they are removed. Hence the ancients imagined that the magnet fed on iron.

A single magnet may be made of two bars of steel, with their ends pressed into close contact; and it might be expected that when these bars are separated, or when a common magnet has been divided in the middle, the portions should possess the properties of the respective poles only. But in fact the ends which have been in contact are found to acquire the properties of the poles opposite to those of their respective pieces, and a certain point in each piece is neutral, which is at first nearer to the newly formed pole than to the other end, but is removed by degrees to a more central situation. In this case we must suppose, contrarily to the general principles of the theory, that the magnetic fluid has actually escaped by degrees from one of the pieces, and has been received from the atmosphere by the other.

There is no reason to imagine any immediate connexion between magnetism and electricity, except that electricity affects the conducting powers of iron or steel for magnetism, in the same manner as heat or agitation. In some cases a blow, an increase of temperature, or a shock of electricity, may expedite a little the acquisition of polarity; but more commonly any one of these causes impairs the magnetic power. Professor Robinson found, that when a good magnet was struck for three quarters of an hour, and allowed in the mean time to ring, its efficacy was destroyed, although the same operation had little effect when the ringing was impeded; so that the continued exertion of the cohesive and repulsive powers appears to favour the transmission of the magnetic as well as of the electric fluid. The internal agitation, produced in bending a magnetic wire round a cylinder, also destroys its polarity, and the operation of a file has the same effect. Mr. Cavallo has found that brass becomes in general much more capable of being attracted when it has been hammered, even between two flints; and that this property is again diminished by fire: in this case it may be conjectured that hammering increases the conducting power of the iron contained in the brass, and thus renders it more susceptible of magnetic action. Mr. Cavallo also observed that a magnetic needle was more powerfully attracted by iron filings during their solution in acids, especially in

the sulphuric acid, than either before or after the operation: others have not always succeeded in the experiment; but there is nothing improbable in the circumstance, and there may have been some actual difference in the results, dependent on causes too minute for observation. In subjects so little understood as the theory of magnetism, we are obliged to omit some paradoxical propositions, which are only surprising on account of the imperfect state of our knowledge. Yet, little as we can understand the intimate nature of magnetical actions, they exhibit to us a number of extremely amusing as well as interesting phænomena; and the principles of crystallization, and even of vital growth and reproduction, are no where so closely imitated, as in the arrangement of the small particles of iron in the neighbourhood of a magnet, and in the production of a multitude of complete magnets, from the influence of a parent of the same kind.

[*Young's Nat. Phil.*

The preceding article, though concise, is so full and explicit upon the curious and recondite subject it is designed to illustrate, that we have but a few notices to subjoin in addition to what it communicates.

The phænomena of electricity have been often accounted for, and are so still by some philosphers, by the existence of two distinct electric fluids, an attractive and a repulsive. Mr. Coulomb contended for the existence of two distinct magnetic fluids, which are only displaced in each molecule. He also found that a wire, when twisted, receives nine times as much magnetic force, as when straight: and that a metal is affected with the magnetic influence, if it contain $\frac{1}{130000}$ part of iron.

Cavallo carried this discovery still farther; for he ascertained that a smaller quantity of iron will affect the needle than can be detected by any chemical test: and we have already had occasion to observe that a flash of lightning will completely reverse its polarity in the mariner's compass*.

Nickel, possibly from its constantly containing some portion of iron, is constituently magnetic: but a mixture of cobalt destroys this power.

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* See Section iii. articles 16, 17, of the preceding chapter.

In like manner Dr. Young has observed, that the polarity of iron itself is destroyed by a mixture of antimony with this last metal.

The *Décade Philosophique*, No. 21, contains an account of various experiments made before the French Imperial Institute, which seem to shew that all bodies are subject to the magnetic influence, even in a degree which is capable of being measured.

These experiments were made by Mr. Coulomb, and repeated by him before the Institute. He employed all the substances that he examined in the form of a cylinder, or a small bar; he suspended them by a thread of silk in its natural state, as spun by the worm, and placed them between the opposite poles of two magnets of steel. Such a thread can scarcely support more than two or three drachms without breaking; it was therefore necessary to reduce these needles to very small dimensions. Mr. Coulomb made them about a third of an inch in length, and about a thirtieth of an inch in thickness; and those of metal only one third as thick.

In making the experiments, he placed the magnets in the same right line. Their opposite poles were separated about a quarter of an inch more than the length of the needle which was to oscillate between them. The result was, that of whatever substance the needles were formed, they always ranged themselves accurately in the direction of the magnets; and if they were deflected from this direction, they returned to it with oscillations, which were often as frequent as thirty or more in a minute. Hence, the weight and figure of the needles being given, it was easy to determine the force that produced these oscillations.

The experiments were made in succession with small plates of gold, silver, copper, lead, and tin; with little cylinders of glass, with a bit of chalk, a fragment of bone, and different kinds of wood.

In the course of his lecture on magnetism on the 30th of April, Dr. Young repeated some of these experiments with wires of different kinds: one of them was of tin, and suspended with a cylindrical glass jar by a single silk-worm's thread: its oscillations were so slow as to occupy several minutes, and it was scarcely affected by turning the cross bar to which the thread was attached; so that the suspension must have been sufficiently delicate: under these circumstances the opposite poles of two strong magnets were ap-

plied close to the jar, and at the distance of about twice the length of the suspended wire: but the effect was absolutely imperceptible: in the morning indeed, there had been an appearance of oscillations occupying about a minute, and tending to the direction of the magnets, perhaps derived from some superficial particles of iron which had lost their magnetic property by oxidation in the course of the day. There must at any rate be a doubt whether the presence of a quantity of iron, too small to be ascertained by chemical tests, might not have been the cause of the effects described by Mr. Coulomb, although they indicate a force something greater, upon a rough calculation than one 2000th of the weight of the substance.

By farther experiments of Mr. Coulomb, however, related in No. 3, tom. iii. of the Bulletin de la Societé Philomatique, and which appear to have been made with great caution, it seems obvious that the greater part, if not the whole, of the magnetic influence observed in the preceding cases, was owing to the presence of iron. For it appears that, according to the method employed in the purification of the metals examined, their apparent magnetic power was very materially different. Mr. Coulomb observes that upon this foundation, we may make the action of the magnet, upon a needle thus suspended, a very useful instrument in chemical examinations; for he finds that the attractive force is directly as the quantity of iron in any mixture; and, according to its magnitude, we may estimate that quantity, when it is so small as wholly to elude all chemical tests.

Many of the properties of the magnet were known at a very early period to the Greek philosophers, and especially to Plato and Epicurus; the latter of whom endeavoured to account for them by an ingenious hypothesis, which is fully detailed by Lucretius. We have not space to enter into this hypothesis; but the poet's minute description of the well-known powers of what we now call the loadstone or artificial magnet, as given at so early a period, cannot fail of being acceptable to our readers. It occurs in his very extraordinary poem *De Rerum Natura*, lib. vi. v. 906:

Quod super est, agere incipiam quo fœdere fiat
Naturæ, lapis hicc' ut ferrum ducere possit,
Quem Magneta vocant patrio de nomine Graiei,
Magnetum quia sit patriis in finibus ortus.

Hunc homines lapidem mirantur, quippe catenam
Sæpe ex annellis reddit pendentibus ex se:
Quinque et enim licet interdum, pluresque, videre,
Ordine demisso, levibus jactarier auris,
Unus ubi ex uno dependet, subter adhærens;
Ex alioque alius lapidis vim, vinclaque, noscit:
Usque adeo permananter vis pervalet ejus.

And next explain we by what curious law
The stone term'd MAGNET by the GREEKS, attracts
Th' obsequious iron; magnet term'd since first
Mid the MAGNETES men its power descried.
Vast is the wonder, mid th' admiring crowd,
This stone excites; for oft a pendant chain
Forms it of rings unlink'd and loosely join'd.
And frequent see they, sporting in the breeze,
Such rings quintupled, in succession long,
The lowlier cleaving to the sphere above,
And this to that, proclaiming, as it hangs,
Its deep-felt conscience of the magnet's power.
Such the resistless energy it boasts. GOOD.

Upon this subject also, we must take leave to subjoin the learned Translator's note on the passage:

"There is nothing in nature too recondite for the daring penetration of our poetic philosopher. The timid mineralogist of modern days cannot, without surprise, behold him thus undauntedly endeavouring to develope a bond, into whose mysterious union he himself feels totally unable to penetrate: and if, in pursuing his hardy footsteps, he perceive the bold speculator, at times, bewildered in a wrong path, he will seldom be able to point out to him a truer.

"Hence, Polignac, to whose negative declaration, neither our poet, nor any modern philosopher, will, probably, object:

Miracula nondum
Omnia magnetis perspeximus; at mihi certum est
Magnetem non esse animal; nec amoris ab æstu
Ferratus trahere, ac secum vincire catenas.

ANTI-LUCR. V. 1156.

For not yet clearly are the wonders trac'd
Prov'd by the magnet; but to me most clear
Seems it no animal; nor led by bonds
Of mutual love t' attract and clasp the steel.

"The ferruginous ore, here spoken of, for it is nothing else than ferruginous ore, with a saturation of magnetic aura, was denominated, as Lucretius observes, magnet, from its having been first noticed among the Magnetes, or inhabitants of Magnesia, a region of Lydia. It is also often entitled Herculeus lapis; either because it was first traced by Hercules, or detected in the vicinity of Heraclea; or, lastly, from the prodigious strength of its attraction. Lucretius, indeed, employs this latter term on no occasion, but Marchetti has introduced it into his version, with a view of varying his phraseology:

——l' Erculla pietra
Con incognita forza il ferro tragga.

"Whether the ancients were acquainted with that most useful nautical instrument to which the properties of this stone have given birth, the mariner's compass, is in some degree doubtful. In modern Europe, we have no decisive knowledge of the existence of this instrument anterior to its use by Marco Polo, in 1260. Among the Chinese, however, it appears to have been employed immemorially; from which circumstance, many scholars of high reputation, and among the rest my learned and indefatigable friend the Rev. T. Maurice, conceives that other ancient nations were in an equal degree acquainted with its utility. They contend, that it was known to the Druids, and that the cardinal points of what they call the Druidic *temples* at Stonehenge and Abury, were determined by the use of such a compass. In like manner, ascribing its name of lapis Heraclius, or Herculeus, to Hercules, as its inventor, they conjecture it was known also to the Greeks; and that the golden cup which Apollo, or the Sun under that denomination, gave to Hercules, was nothing more or less than the mariner's compass-box, *by* which, not *in* which, the latter sailed over the vast ocean; they add also, that the golden fleece and the golden scyphus in the temple of Jupiter Ammon in Lybia, were nothing more than types of this curious instrument. I am afraid,

however, there is more ingenuity in such conjectures than solid argument or historic fact: and in addition to the observations advanced on the other side of the question by Sir William Temple, Dr. Wotton, and Mr. Clarke, I cannot avoid remarking, that had this instrument been known in the time of Lucretius, he would not have failed to have adverted to it on the present occasion. But it is neither mentioned by Lucretius nor by Suidas."

[Editor.

SECTION II.

On the Cause of the Change in the Variation of the Magnetic Needle; with an Hypothesis of the structure of the internal parts of the Earth.

By Mr. Edmund Halley.

Having published, in the Transactions, N 148, a theory of the variation of the magnetic needle, in which, by comparing many observations, I came at length to this general conclusion, viz. That the globe of the earth might be supposed to be one great magnet, having four magnetical poles or points of attraction, two of them near each pole of the equator: and that in those parts of the world, which lie near any of those magnetical poles, the needle is chiefly governed thereby, the nearest pole being always predominant over the more remote. And I there endeavoured to state and limit the present position of those poles on the surface of our globe. Yet I found two difficulties not easy to surmount: the one was, that no magnet, I had ever seen or heard of, had more than two opposite poles; whereas the earth had visibly four, and perhaps more. And secondly, it was plain that these poles were not, at least all of them, fixed in the earth, but shifted from place to place, as appeared by the great changes in the needle's direction within this last century of years, not only at London, where this great discovery was first made, but almost all over the globe of the earth,; whereas it is not known, or observed, that the poles of a loadstone ever shifted their place in the stone, nor, considering the compact hardness of their substance, can it easily be supposed.

These difficulties made me quite despair of ever being able to ac-

count for this phænomenon, when in an accidental conversation I stumbled on the following hypothesis. It is sufficiently known and allowed, that the needle's variation changes; and that this change is gradual and universal, will appear by the following examples. At London, in the year 1580, the variation was observed by Mr. Burrows to be 11° 15′ to the east; in 1622, the same was found by Mr. Gunter to be only 6° 0′ to the east; in 1634, Mr. Gellibrand found it at 4° 5′ to the east; in 1657, Mr. Bond observed that there was no variation at London; anno 1762, I observed it 2° 30′ to the west; and this present year 1692, I again found it 6° to the west. So that, in 112 years, the direction of the needle has changed no less than seventeen degrees.

At Paris, Orontius Finæus, about the year 1550, reckoned it about 8° or 9° eåst variation; in 1640, it was found 3° to the east; in 1666 there was no variation there; and in 1681, I found it to be 2° 30′ to the west.

At Cape d'Agulhas, the most southerly promontory of Africa, about the year 1600, the needle pointed due north and south without variation, whence the Portuguese gave it that name; in 1622 there was 2° west variation; in 1675 it was 8° to the west; and this year 1691, it was accurately observed to be not less than 11° to the west.

At St. Helena, about the year 1600, the needle declined 8° to the east; in 1623, it was but 6° to the east; in 1677, when I was there, I observed it accurately on shore to be 40′ east; and now this year it was about 1° to the westward of the north.

At Cape Comorin, in India, in the year 1620, there were 14° 20′ west variation; in 1680, there was 8° 48′; but in 1668, it was no more than 7° 30′; so that here the needle has returned to the east about 7° in seventy years.

In all the other examples the needle has gradually moved towards the west, and the places are too far asunder to be influenced by the removal of any magnetical matter, which may by accident be transplaced within the bowels or on the surface of the earth. From these, and many other observations, it is evident that the direction of the needle is in no place fixed and constant, though in some it changes faster than in others. And where for a long time it has continued as it were unaltered, it is there to be understood that the needle has its greatest deflection, and is become stationary, in or-

der to return, like the sun in the tropics. This at present, viz. 1692, is in the Indian sea, about the island Mauritius, where is the highest west variation, and in a tract tending from thence to the N. N. W. towards the Red Sea and Egypt. And in all places to the westward of this tract, all over Africa and the seas adjoining, the west variation will be found to have increased; and to the eastwards thereof, as in the example of Cape Comorin, to have decreased, viz. all over the East Indies and the islands near it.

In like manner, in that space of east variation, which, beginning near St. Helena, is found all over South America, and which at present is highest about the mouth of Rio de la Plata, it has been observed, that in the eastern parts of it, the variation of the needle gradually decreases; but whether, on the contrary, it increases in those places which lie more westerly than that tract wherein the highest east variation is found; or how it may be in the vast Pacific Sea, we have not experience enough to ascertain; only we may by analogy infer, that both the east and west variations gradually increase and decrease after the same rule.

These phænomena, being well understood and duly considered, sufficiently evince, that the whole magnetical system has one, or perhaps more motions; that the moving force is very great, as extending its effects from pole to pole; and that its motion is not per saltum, but a gradual and regular motion.

Now considering the structure of our terraqueous globe, it cannot be well supposed that a very great part of it can move within it, without notably changing its centre of gravity, and the equilibrium of its parts, which would produce very wonderful effects in changing the axis of diurnal rotation, and occasion strange alteration in the surface of the sea, by inundations and recessions, such as history never yet mentioned. Besides the solid parts of the earth are not to be supposed permeable by any other than fluid substances, of which we know none that are any ways magnetical. So that the only way to render this motion intelligible and possible, is, to suppose it to turn about the centre of the globe, having its centre of gravity fixed and immoveable in the same common centre of the earth: and there is yet required, that this moving internal substance be loose, and detached from the external parts of the earth, whereon we live; for otherwise, were it affixed to the earth, the whole must necessarily move together.

So then the external parts of the globe may well be considered as the shell, and the internal as a nucleus, or inner globe, included within ours, with a fluid medium between. Which having the same common centre and axis of diurnal rotation, may turn about with our earth each twenty-four hours; only this outer sphere having its turbinating motion some small matter either swifter or slower than the internal ball. And a very minute difference in length of time, by many repetitions becoming sensible, the internal parts will by degrees recede from the external, and not keeping pace with each other, will appear gradually to move either to the east or west by the difference of their motions.

Now supposing such an internal sphere, having such a motion, we may solve the two great difficulties in my former hypothesis. For if this exterior shell of earth be a magnet, having its poles at a distance from the poles of diurnal motion; and if the internal nucleus be likewise a magnet, having its poles in two other places distant also from the axis; and these latter, by a gradual and slow motion, change their place in respect of the external, we may then give a reasonable account of the four magnetical poles, as also of the changes of the needle's variations.

The period of this motion being wonderfully great, and there being hardly a century since these variations have been duly observed, it will be very hard to bring this hypothesis to a calculus, especially since, though the variations increase and decrease regularly in the same place, yet in different places, at no great distance, there are found such casual changes of it, as can nowise be accounted for by a regular hypothesis; as depending on the unequal and irregular distribution of the magnetical matter within the substance of the external shell or coat of the earth, which deflects the needle from the position it would acquire from the effect of the general magnetism of the whole. Of this, the variations at London and Paris afford a notable instance; for the needle has been constantly about $1\frac{1}{2}°$ more easterly at Paris than at London; though it be certain that, according to the general effect, the difference ought to be the contrary way. Notwithstanding which, the variation in both places changes alike.

Hence, and from some other of the like nature, I conclude, that the two poles of the external globe are fixed in the earth, and that if the needle were wholly governed by them, the variations would

be always the same, with some little irregularities on the account just now mentioned: but the internal sphere, having such a gradual translation of its poles, influences the needle, and directs it variously, according to the result of the attractive or directive power of each pole; and consequently there must be a period of the revolution of this internal ball, after which the variations will return again as before. But if it shall in future ages be observed otherwise, we must then conclude, that there are more of these internal spheres, and more magnetical poles than four, which at present we have not a sufficient number of observations to determine, and particularly in that vast Mar del Zur, which occupies so great a part of the whole surface of the earth.

If then two of the poles be fixed, and two moveable, it remains to ascertain which they are that keep their place: and though I could wish we had the experience of another century of years to found our conclusions upon, yet I think we may safely determine, that our European north pole, supposed to be near the meridian of the Land's End, and about 7 from it, is that which is moveable of the two northern poles, and which has chiefly influenced the variations in these parts of the world: for in Hudson's Bay, which is under the direction of the American pole, the change is not observed to be near so fast as in these parts of Europe, though that pole be much farther removed from the axis.

As to the south poles, from the like observation of the slow decrease of the variation on the coast of Java, and near the meridian of the Asian pole, I take the Asiatic pole, which I place about the meridian of the island of Celebes, to be the fixed one, and consequently the American pole to be moveable. If this be allowed, it is plain that the fixed poles are the poles of this external shell or cortex of the earth, and the other two the poles of a magnetical nucleus, included and moveable within the other. It likewise follows, that this motion is westwards, and by consequence that the aforesaid nucleus has not precisely attained the same degree of velocity with the exterior parts in their diurnal revolution: but so very nearly equals it, that in 365 revolves the difference is scarcely sensible. This I conceive to arise from the impulse by which this diurnal motion was impressed on the earth, being given to the external parts, and from thence in time communicated to the internal; but not so as perfectly to equal the velocity of the first motion

impressed on and still conserved by the superficial parts of the globe.

As to the quantity of this motion it is almost impossible to define it, both from the nature of this kind of observation, which cannot be very accurately performed; as also from the small time these variations have been observed, and their change discovered. It appears by all circumstances, that its period is of many centuries of years, and as far as may be collected from the change of the place, where there was no variation by reason of the equilibrium of the two southern magnetical poles, viz. from Cape d'Agulhas to the meridian of St. Helena, which is about 23° in about ninety years, and of the place where the westerly variation is in its greatest deflection, being about half so much, viz. from the isle of Diego Roiz to the south-west parts of Madagascar. We may with some reason conjecture, that the American pole has moved westwards 46° in that time, and that the whole period of its variation is performed in 700 years, or thereabouts; so that the nice determination of this, and of several other particulars in the magnetic system, is reserved for remote posterity; all that we can hope to do, is to leave behind us observations that may be confided in, and to propose hypotheses which after ages may examine, amend, or refute. Only here I must take leave to recommend to all masters of ships and all others, lovers of natural truths, that they use their utmost diligence to make, or procure to be made, observations of these variations in all these parts of the world, as well in the north as south latitude, after the laudable custom of our East India commanders, and that they please to communicate them to the Royal Society, in order to leave as complete a history as may be, to those who are hereafter to compare all together, and to complete and perfect this abstruse theory.

And by the way it will not be amiss to correct a received error in the practice of observing the variation, which is, to take it by the amplitude of the rising and setting sun, when his centre appears in the visible horizon; whereas he ought to be observed when his under limb is still above the horizon about two-thirds of his diameter, or twenty minutes, on account of the rarefaction, and the height of the eye of the observer above the surface of the sea: or else the amplitudes are to be wrought as the azimuths, reckoning the sun's distance from the zenith 90° 36′: this, though it be of

little consequence near the equator, will make a great error in high latitudes, where the sun rises and sets obliquely.

But to return to our hypothesis, in order to explain the change of the variations, we have adventured to make the earth hollow, and to place another globe within it: and I doubt not but this will find opposers enough. I know it will be objected, that there is no instance in nature of the like thing; that if there was such a middle globe it would not keep its place in the centre, but be apt to deviate from it, and might possibly shock against the concave shell, to the ruin or at least endamaging of it; that the water of the sea would perpetually leak through, unless we suppose the cavity full of water; that were it possible, yet it does not appear of what use such an inward sphere can be of, being shut up in eternal darkness, and therefore unfit for the production of animals or plants; with many more objections, according to the fate of all such new propositions.

To these and all other objections that I can foresee, I briefly answer, that the ring environing the globe Saturn is a notable instance of this kind, as having the same common centre, and moving along with the planet, without sensibly approaching him on one side more than the other. And if this ring were turned on one of its diameters, it would then describe such a concave sphere as I suppose our external one to be. And since the ring in any given position, would in the same manner keep the centre of Saturn in its own, it follows that such a concave sphere may move with another included in it, having the same common centre. Nor can it well be supposed otherwise, considering the nature of gravity: for should these globes be once adjusted to the same common centre, the gravity of the parts of the concave would press equally towards the centre of the inner ball, which equality must necessarily continue till some external force disturb it, which is not easy to imagine in our case. This perhaps I might more intelligibly express, by saying that the inner globe being deposited in the centre of the exterior, must necessarily ascend which way soever it may move; that is, it must overcome the force of gravity pressing towards the common centre, by an impulse it must receive from some outward agent; but all outward efforts being sufficiently fenced against by the shell that surrounds it, it follows, that this nucleus being once fixed in the common centre, must always remain there.

As to the leaking of the water through this shell, when once a passage shall be found for it to run through, I must confess it is an objection seemingly of weight; but when we consider how tightly great beds of chalk or clay, and much more stone do hold water, and even caves arched with sand; no man can doubt but the wisdom of the Creator has provided for the microcosm by many more ways than I can either imagine or express, especially since we see the admirable and innumerable contrivances wherewith each worthless individual is furnished, both to defend itself and propagate its species. What curiosity in the structure, what accuracy in the mixture and composition of the parts, ought we not to expect in the fabric of this globe, designed for the lasting habitation of so many various species of animals, in each of which there want not many instances, that manifest the boundless power and goodness of their divine author; and can we then think it a hard supposition, that the internal parts of this bubble of earth should be replete with such saline and vitriolic particles, as may contribute to petrifaction, and dispose the transuding water to shoot and coagulate into stone, so as continually to fortify, and if need were, to consolidate any breach or flaw in the concave surface of the shell.

And this perhaps may not without reason be supposed to be the final cause of the admixture of the magnetical matter in the mass of the terrestrial parts of our globe, viz. To strengthen and maintain the concave arch of this shell: for, by what the excellent Mr. Newton has shown in his Principia Philosophiæ, it will follow that according to the general principle of gravity, visible throughout the whole universe, all those particles which, by length of time or otherwise, shall moulder away, or become loose on the concave surface of the external sphere, would fall in, and with great force descend on the internal, unless those particles were of another sort of matter, capable, by their stronger tendency to each other, to suspend the force of gravity; but we know no other substances capable of supporting each other by their mutual attraction, besides the magnetical, and these we see miraculously to perform that office, even when the power of gravity has its full effect, much more within the globe where it is weaker. Why then may we not suppose these said arches to be lined throughout with a magnetical matter, or rather to be one great concave magnet, whose two poles are the poles we have before observed to be fixed in the surface of our globe?

Another argument, favouring this hypothesis, is drawn from a proposition of the same Mr. Newton, where he determines the force with which the moon moves the sea in producing the tides, where he says the density of the moon is to that of the earth as 680 to 387, or as 9 to 5 nearly : therefore the body of the moon is denser than our earth, &c. Now if the moon be more solid than the earth, as 9 to 5, why may we not reasonably suppose the moon, being a small body and a secondary planet, to be solid earth, water, and stone, and this globe to consist of the same materials, only four-ninths thereof to be cavity, within and between the internal spheres.

To those that shall inquire of what use these included globes can be, it must be allowed, that they can be of very little service to the inhabitants of this outward world ; nor can the sun be serviceable to them, either with his light or heat. But since it is now taken for granted that the earth is one of the planets, and that they all are with reason supposed habitable, though we are not able to define by what sort of animals ; and since we see all the parts of the creation abound with animate beings, as the air with birds and flies, the water with the numerous varieties of fish, and the very earth with reptiles of so many sorts ; all whose ways of living would be to us incredible, did not daily experience teach us ; why then should we think it strange that the prodigious mass of matter, of which this globe consists, should be capable of some other improvements, than barely to serve to support its surface ? Why may not we rather suppose that the exceeding small quantity of solid matter, in respect of the fluid ether, is so disposed by the Almighty wisdom, as to yield as great a surface for the use of living creatures, as can consist with the conveniency and security of the whole ?

But still it may be said, that without light there can be no living, and therefore all this apparatus of our inward globes must be useless : to this I answer, that there are many ways of producing light, which we are wholly ignorant of ; the medium itself may be always luminous, after the manner of our ignis fatui. The concave arches may in several places shine with such a substance, as invests the surface of the sun ; nor can we without a boldness unbecoming a philosopher, adventure to assert the impossibility of peculiar luminaries below, of which we have no sort of idea.

Lastly, to explain yet farther what I mean, let us suppose our own globe to consist of four different circles : that the surface of

the earth is represented by the outward circle, and that the three inner circles are made nearly proportionable to the magnitudes of the planets Venus, Mars, and Mercury, all which may be included within this globe of the earth, and all the arches be more than sufficiently strong to bear their weight. The concave of each arch, which is shaded differently from the rest, we may suppose to be made up of magnetical matter; and the whole to turn about the same common axis; only with this difference, that the outer sphere still moves somewhat faster than the inner. Thus, the diameter of the earth being about 8000 English miles, I allow 500 miles for the thickness of its shell, and another space of 500 miles for a medium between, capable of an immense atmosphere for the use of the globe of Venus. Venus again I give a shell of the same thickness, and leave as great a space between her concave and Mars; so likewise from Mars to Mercury, which latter ball we will suppose solid, and about 2000 miles diameter.

Since this was written, a discovery I have made in the celestial motions, seems to render a farther account of the use of the cavity of the earth, viz. To diminish its specific gravity in respect of the moon: for I think I can demonstrate, that the opposition of the ether to the motions of the planets, in long time becomes sensible; and consequently the greater body must receive a less opposition than the smaller, unless the specific gravity of the smaller do proportionably exceed that of the greater, in which case only they can move together; so that the cavity I assign in the earth may well serve to adjust its weight to that of the moon; for otherwise the earth would leave the moon behind it, and she become another primary planet.

[*Phil. Trans.* 1692.

SECTION III.

Magnetical Experiments.

1. *By Mr. Sellers**.

On Magnetic Needles.

Mr. Sellers states, that he had often made trial with many needles, touching them on each hemisphere of the stone, in all variety of ways he could imagine, to find if it were possible, by that means, to cause any of those needles to vary in its direction: but that he always found the contrary, all of them conforming to the magnetical meridian, and standing north and south, as other needles that were touched on the very pole of the stone. He adds, that some of these experiments he tried in London, when there was no variation known.

That on frequent trials of touching needles with different load-stones of several magnitudes, as also of different virtue, the needles touched gave all of them the same directions. This he thinks is confirmed by all the needles, and sea compasses, made in several parts of the world, and consequently touched on several stones of different countries, yet all agreeing in this magnetical harmony, that they all give the same directions. That having sometimes drawn a needle only over the pole of the stone, within the sphere of its virtue, without touching the stone, it has received the same directive quality from the stone as if it had been really touched on the stone itself, though not altogether so strong as if it had touched the stone. Again, that having touched needles on the stone with faint strokes, and other needles with stronger, all these needles received the same effect from the stone, both for strength and direction; he conceiving that it is not the fainter or stronger touches on the stone, nor the multiplicity of strokes, that varies the needle's strength or direction; but that the nature of the steel whereof the needle is made, and the temper that is given thereunto, cause different effects as to the strength it receives from the stone; himself having tried all sorts of steel that he could possibly procure, and all the different tempers he could imagine, for

* This seems to be the first notice of making artificial magnets. Mr. Sellers is probably the person of the same name who was the author of Practical Navigation, in 1669.

the most powerful receiving and retaining the virtue from the load-stone; he also affirms that he has fully satisfied himself that he can infuse such virtue into a piece of steel, that it shall take up a piece of iron of two ounces weight or more; and give also to a needle the virtue of conforming to the magnetical meridian, without the help of a loadstone or any thing else that has received virtue therefrom.

[*Phil. Trans. Abr.* 1667.

2. *By Mr. (afterwards Dr.) Gowan Knight; shewn before the Royal Society, November* 15, 1774 *.

Mr. Knight, of Magdalen College, Oxford, being introduced to a meeting of the Royal Society on Thursday the 15th of November, 1744, produced, before the gentlemen there present, several curious artificial magnets contrived by himself; some of which consisted of plain bars of steel naked, and others of bars or blocks of the same substance, armed with iron after the common manner of natural loadstones: but as he was apprehensive the trials he had before made of the weights these magnets were respectively capable of lifting could hardly be repeated with sufficient exactness, and advantage before so large a company, he desired to refer himself, for those particulars, to what the president of the Society had seen at his lodgings on Wednesday the 7th, and on Tuesday the 13th of the same month of November.

On which the president acquainted the company, that he had lately been several times at Mr. Knight's lodgings, where he had seen many experiments made with his artificial magnets; and that, particularly on the days above-mentioned, he had been present, and had taken minutes of the following trials then made by that gentleman, by which it appeared, that—

A small eight-cornered bar of steel, of the length of 7-10th inches, and about half an ounce Troy weight, lifted by one of its ends about eleven of the same ounces.

That another plain bar of steel, of a parallelopiped form, of the length of 5 9-10th inches, the breadth 4-16ths, and the thickness

* There is another paper containing an additional series of experiments on the same subject, made by the same experimentists, contained in vol. xliv. year 1747, of the Transactions; but it is not much more than an expansion of those presented above. EDITOR.

2-10ths of an inch, weighing 2 oz. $8\frac{1}{2}$ dwt. lifted by one of its ends twenty Troy ounces.

That a steel bar, almost of the same form as the last, but only four inches in length, capped or armed with iron at each end, cramped with silver, and weighing all together 1 oz. 14 dwt. lifted by the feet of the armour full 4 lb. Troy.

That a single block of steel of a parallelopiped form, almost four inches long, 1 2-10th inches in height, and 4-10ths of an inch in thickness, armed with iron, cramped with brass, suspended by a ring of the same, and weighing altogether 14 oz. 1 dwt. lifted by the feet of the armour 14 lb. $2\frac{1}{2}$ oz. Troy weight.

That a compound artificial magnet was also tried, consisting of twelve bars of steel armed, and that it was found to lift by the feet of the armour, as the last, 23 lb. Troy, $2\frac{1}{2}$ oz.

The twelve bars, composing this last magnet, were each a little more than four inches long, 3-10ths of an inch in breadth, and 16-100ths of the same in depth, weighing one with another about 25 dwt. each. They were all placed one on another, so as to make together one parallelopiped body, of the common length and breadth of the several bars, but of the height of near two inches, being the sum of the respective thicknesses of all the bars taken together: and this parallelopiped body, being cramped with brass and fitted with a handle of the same metal, was armed at the two ends that were made up of the common extremities of all the bars, with two substantial pieces of iron, after the common manner of arming natural loadstones, the whole frame weighing together about twenty ounces Troy.

Besides these, the president made also the following report of some trials he had seen made at the same time of the effects of an art Mr. Knight is master of, by which he can improve or increase the lifting powers of natural loadstones.

He carried with him, on Wednesday the 7th of November, a small armed loadstone belonging to an acquaintance, which weighed, with its armour, 7 dwt. 14 grains; but which, being reputed but of an ungenerous nature, took up, and with some difficulty, barely two inches. Mr. Knight took it into his study, and returning it in about a minute, it then took up more than four ounces with ease: but, on his saying it would still gain some more strength, by remaining with him some time, it was left till the 13th, when it

took up distinctly, with the same apparatus as before, 6 oz. 18 dwt. 3 grains; since which time it has also several times been found to lift nearly the same quantity.

Mr. Knight further, at the same time, showed the president the following instances of his ability to invert or change the direction of the poles in natural loadstones.

Such a stone belonging to Mr. Francis Hauksbee, weighing about 5 oz. 14 dwts. of an irregular cylindrical form, with two of the sides somewhat flatted, on which armour had formerly been applied, had the direction of its polarity from one of these flatted sides to the other, notwithstanding the stone had a distinct grain running at right angles to that direction. It was tried, and observed that one of these flatted sides strongly attracted the north end, and repelled the south; and that the other attracted the south, and repelled the north end of the magnetic needle. The end of the stone, attracting the south end of the needle, was then marked, by the rubbing of a piece of a silver upon it, as on a touch-stone: after which, Mr. Knight carried the stone into his study; and reproducing it in about a minute, showed that the poles were then directly inverted; and that the same end, which before attracted the south end of the needle, now attracted the north, and repelled the south, and vice versâ.

After this, Mr. Knight, again taking the stone, brought it back in as short a time as before, with the direction of its polarity turned at right angles to its former direction, and into the direction of the natural grain of the stone, the poles now lying in the flat ends of the cylinder; one of which, being the smoother end, attracted the south end of the needle, while the other, which was of a rougher texture, attracted the north end, and repelled the south end of the same: when it was also observed, that the polarity appeared stronger in this case than either of the former.

Lastly, Mr. Knight, in about the same time, inverted this last direction of the poles, keeping it still parallel to the axis of the cylinder, but causing the smooth end of the stone to attract the north end of the magnetic needle, and the rough end to attract the south, and repel the north end of the same needle.

After this report, Mr. Knight proceeded to show, at the meeting, some of the same artificial magnets there mentioned; and it was found, that the compound magnet, consisting of twelve steel bars, and which had, in the experiment made before the president,

lifted 23lb. $2\frac{1}{2}$ oz. Troy weight, did here, under all the inconveniencies and disadvantages of a crowded room, still lift a weight amounting to 21 lb. 11 oz.

It was also found, that the single armed block of steel, which had before lifted 14 lb. 2 oz. did here, under the same disadvantages as the former, lift 13 lb. 7 oz.

And lastly, Mr. Knight produced to the company the above-mentioned natural loadstone belonging to Mr. Hauksbee, but with the direction of its polarity again altered from what it was, when it was last seen by the president.

P. S. Since the artificial magnets mentioned in the foregoing paper, Mr. Knight has caused some others to be made of a less size, but of a very great lifting power: and one of these, weighing without its armour, just an ounce, and with the armour, cramps, and rings, 1 oz. 17 dwt. lifted 6 lb. 10 oz.

This magnet consisted of three plates of steel, each two inches long, 7-10ths of an inch in breadth, and not above 6-100ths of an inch in thickness: they were laid flat on each other, and screwed together by two small brass screws going through the three plates. After which, the little parallelopiped block so made up, was armed with iron at the two ends, cramped together with silver, and fitted with a double ring of the same metal, for the convenient holding of it.

[*Phil. Trans.* 1744.

3. *By Mr. Benjamin Wilson.*

Containing an account of Dr. Knight's method of making artificial Loadstones.

The method was this: having provided himself with a large quantity of clean filings of iron, Dr. K. put them into a large tub that was more than one-third filled with clean water; he then, with great labour, worked the tub to and fro for many hours together, that the friction between the grains of iron by this treatment might break off such smaller parts as would remain suspended in the water for some time: the obtaining of which very small particles in sufficient quantity seemed to him to be one of the principal desiderata in the experiment. The water being by this treatment rendered very muddy, he poured it into a clean earthen vessel, leaving the filings behind; and when the water had stood long enough to

become clear, he poured it out carefully, without disturbing such of the iron sediment as still remained, which now appeared reduced almost to impalpable powder. This powder was afterwards removed into another vessel, in order to dry it; but as he had not obtained a proper quantity of it by this first step, he was obliged to repeat the process many times.

Having at last procured enough of this very fine powder, the next thing to be done was to make a paste of it, and that with some vehicle which would contain a considerable quantity of the phlogistic principle: for this purpose he had recourse to linseed oil in preference to all other fluids. With these two ingredients only, he made a stiff paste, taking a particular care to knead it well before he moulded it into convenient shapes. Sometimes, while the paste continued in its soft state, he would put the impression of a seal on the several pieces; one of which is in the British Museum. This paste was then put upon wood, and sometimes on tiles, in order to bake or dry it before a moderate fire, at about a foot distance. The doctor found, that a moderate fire was most proper, because a greater degree of heat made the composition frequently crack in many places.

The time required for the baking or drying of this paste was generally five or six hours, before it attained a sufficient degree of hardness. When that was done, and the several baked pieces were become cold, he gave them their magnetic virtue in any direction he pleased, by placing them between the extreme ends of his large magazine of artificial magnets for a few seconds or more, as he saw occasion. By this method the virtue they acquired was such, that when any one of those pieces was held between two of his best ten guinea bars, with its poles purposely inverted, it immediately of itself turned about to recover its natural direction, which the force of those very powerful bars was not sufficient to counteract.

[*Phil. Trans.* 1779.

CHAP. XLV.

AURORA BOREALIS AND AUSTRALIS.

SECTION I.

General History and Remarks.

The reader who carefully attends to the different sections of the present chapter, will see the propriety of our having preceded it by a chaper explanatory of the general laws and phænomena of magnetism: since he will find sufficient reason, if we mistake not, for concurring in the general opinion of the day, that this splendid meteor is the result of a combination of the two powers of magnetism and electricity.

When the *light* or *aurora* appears chiefly in the north part of the heavens, it is Aurora Borealis, or Northern Lights; and when chiefly in the south part, Aurora Australis, or Southern Lights. Where the corruscation is more than ordinarily bright and streaming, which, however, seldom occurs except in the north, it is denominated Lumen Boreale; and where these streams have assumed a decided curvature, like that of the rainbow, they are distinguished by the name of Luminous Arches.

The Aurora is chiefly visible in the winter season and in frosty weather. It is usually of a reddish colour, inclining to yellow, and sends out frequent corruscations of pale light, which seem to rise from the horizon in a pyramidical, undulating form, shooting with great velocity up to the zenith. This meteor never appears near the equator, but of late years has frequently been seen toward the south pole, and when in that situation is, as above, called *Aurora Australis*, or southern lights; though this is to use the same term in two different senses.

It seems that the aurora borealis has appeared at some periods more frequently than at others. They were so rare in England, or else were so little regarded, that none are recorded in our annals

between a remarkable one observed on the 14th November 1574, and a very brilliant one on the 6th of March, 1716, and the two succeeding nights, but much the strongest on the first night, except that five small ones were noticed in the years 1707 and 1708. Hence it may be inferred, that either the air or earth, or perhaps both, are not at all times in such a state as tends to produce this phenomenon.

The extent of these appearances are also amazingly great; that in March, 1716, was visible from the west of Ireland to the confines of Russia, and the east of Poland, extending over, at least, thirty degrees of longitude, and from about the fiftieth degree of latitude over almost all the northern part of Europe; and in all places, at the same time, it exhibited the like wonderful features. Father Boscovich determined the height of an aurora borealis observed by the Marquis of Polini, 16th December, 1737, and found it 825 miles high; and M. Bergman, from a mean of thirty computations, makes the average height to be 70 Swedish, or 469 English miles. Euler supposes the aurora to be more than double that height; but in this opinion he stands alone; for M. Mairan, in a treatise which he wrote expressly upon this phenomenon, entitled, "Traité Physique et Historique de l'Aurore Boreale," fixes the height, on an average, at 175 leagues from the earth, which is equal to 464 English miles.

Many conjectural opinions have been formed concerning the cause of this phenomenon; Dr. Halley imagined that the watery vapours, or effluvia, exceedingly rarefied by subterraneous fire, and singed with sulphurous streams, which many naturalists have supposed to be the cause of earthquakes, might also be the cause of this appearance; or that it is produced by a kind of subtile matter freely pervading the pores of the earth, and which entering into it near the southern pole, passes out again with some force, into the ether, at the same distance from the northern. The subtile matter, by becoming more dense, or having its velocity increased, may perhaps be capable of producing a small degree of light, after the manner of effluvia from electric bodies, which by a strong and quick friction emits light in the dark, to which sort of light the aurora seems to bear a great affinity. [*Phil. Trans.* *No.* 347.

M. de Mairan, in the treatise above quoted, supposed its cause

to be zodiacal light; which, according to him, is no more than the sun's atmosphere: this light, happening on some occasions to meet the upper parts of our hemisphere, about the limits where universal gravity begins, which it passes. On the contrary, Euler conceived its cause to be particles of our atmosphere driven beyond their limits by the impulse of the solar light. He supposes the zodiacal light and the tails of comets to have a similar origin.

But ever since the identity of lightning and of electric matter has been determined, philosophers have been led to seek for the explication of the aurora wholly, or for the most part, in the principles of electricity. Beside the more obvious and known appearances which constitute a resemblance between this meteor and the electric matter by which lightning is produced, it has been observed that the aurora, like lightning, occasions a very sensible fluctuation in the magnetic needle; and that when it has extended lower than usual in the atmosphere, the corruscations have been attended with various sounds of rumblings and hissing, especially in Russia, and the other more northern parts of Europe, as noticed by Signior Beccaria and M. Messier. Mr. Canton, soon after he obtained electricity from the clouds, offered a conjecture that the aurora is occasioned by the dashing of electric fire in positive toward negative clouds, at a great distance through the upper part of the atmosphere, where the resistance is least; and adds that the aurora is said by the northern people to be remarkably strong when a sudden thaw happens after severe cold. The best paper upon this subject is that which was written by Dr. Franklin, and read to the Royal Academy of Sciences at Paris, in 1779; entitled by him "Suppositions and Conjectures towards forming an hypothesis for the explanation of the Aurora Borealis." His reasoning is as follows: "Air heated by any means becomes rarefied, and specifically lighter than other air in the same situation not heated; and when lighter it rises, and the neighbouring cooler and heavier air takes its place. If in the middle of a room you heat the air by a stove, or pot of burning coals, near the floor, the heated air will rise to the ceiling, spread over the cooler air till it comes to the cold walls; there being condensed and made heavier, it descends, to supply the place of that cool air which had moved towards the stove or fire, in order to supply the place of the heated air which had descended. Thus there will

be a continual circulation of air in the room, which may be rendered visible by making a little smoke, for that smoke will rise and circulate with the air.

" A similar operation is performed by nature on the air of this globe. Above the lower regions of our atmosphere the air is so rare as almost to be a vacuum. The air heated between the tropics is continually rising; its place is supplied by northerly and southerly winds which come from the cooler regions. The light heated air floating above the cooler and denser, must spread northward and southward, and descend near the two poles, to supply the place of the cool air, which had moved towards the equator. Thus a circulation of air is kept up in our atmosphere, as in the room above-mentioned. That heavier and lighter air may move in currents of different and opposite directions, appears sometimes by the clouds that happen to be in those currents, as plainly as by the smoke in the experiment above-mentioned; also, in opening a door between two chambers, one of which has been warmed, by holding a candle near the top, near the bottom, and near the middle, you will find a strong current of warm air passing out of the warmed room above, and another of cool air entering below, while in the middle there is little or no motion.

" The great quantity of vapour rising between the tropics forms clouds, which contain much electricity; some of them fall in rain, before they come to the polar regions. Every drop brings down some electricity with it; the same is done by snow or hail; the electricity so descending, in temperate climates, is received and imbibed by the earth. If the clouds be not sufficiently discharged by this gradual operation, they sometimes discharge themselves suddenly, by striking into the earth, where the earth is fit to receive their electricity, The earth, in temperate and warm climates, is generally fit to receive it, being a good conductor.

" The humidity contained in all the equatorial clouds that reach the polar regions, must there be condensed, and fall in snow. The great cake of ice that eternally covers those regions may be too hard frozen to permit the electricity, descending with that snow, to enter the earth. It may therefore be accumulated upon that ice. The atmosphere being heavier in the polar regions than in the equatorial, will there be lower; as well from that cause, as from the smaller effect of the centrifugal force: consequently

the distance of the vacuum above the lower part of the atmosphere will be less at the poles than elsewhere, and probably much less than the distance (upon the surface of the globe) extending from the pole to those latitudes in which the earth is so thawed as to receive and imbibe electricity. May not then the great quantity of electricity brought into the polar regions by the clouds, which are condensed there, and fall in snow, which electricity would enter the earth, but cannot penetrate the ice; may it not, as a bottle overcharged, break through that low atmosphere, and run along in the vacuum over the air towards the equator; diverging as the degrees of longitude enlarge; strongly visible where densest, and becoming less visible as it more diverges; till it finds a passage to the earth in more temperate climates, or is mingled with the upper air? If such an operation of nature were really performed, would it not give all the appearances of an aurora borealis? And would not the auroras become more frequent after the approach of winter; not only because more visible in longer nights, but also because in summer the long presence of the sun may soften the surface of the great ice-cake, and render it a conductor, by which the accumulation of electricity in the polar regions will be prevented?

"The atmosphere of the polar regions being made more dense by the extreme cold, and all the moisture in that air being frozen, may not any great light arising therein, and passing through it, render its density in some degree visible during the night time, to those who live in rarer air of more southern latitudes? And would it not in that case, although in itself a complete and full circle, extending perhaps ten degrees from the pole, appear to spectators so placed (who could see only a part of it) in the form of a segment, its chord resting on the horizon, and its arch elevated more or less above it, as beheld from latitudes more or less distant; darkish in colour, but yet sufficiently transparent to permit some stars to be seen through it.

"The rays of electric matter issuing out of a body, diverge by mutually repelling each other, unless there be some conducting body near to receive them: and if that conducting body be at a greater distance, they will first diverge, and then converge, in order to enter it. May not this account for some of the varieties of figures, seen at times, in the motions of the luminous matter of

the auroras: since it is possible, that in passing over the atmosphere from the north, in all directions or meridians, towards the equator, the rays of that matter may find, in many places, portions of cloudy region, or moist atmosphere under them, which (being in the natural or negative state) may be fit to receive them, and towards which they may therefore converge: and when one of those receiving bodies is more than saturated, they may again diverge from it, towards other surrounding masses of such humid atmosphere, and thus form the crowns, as they are called, and other figures mentioned in the histories of this meteor?"

That similar corruscations are frequently visible in southern latitudes was not known until Captain Cook made his first voyage round the world. He speaks of an appearance of this kind on the 16th of September, 1770, about ten o'clock at night; it consisted of a dull, reddish light, and reached about twenty degrees above the horizon; its extent was very different at different times, but it was never less than eight or ten points of the compass. Through and out of this, passed rays of light of a brighter colour, which vanished and were renewed nearly in the same time as those in the aurora borealis, but had little or no vibration. The body of it bore S. S. E. from the ship, and continued without any diminution of its brightness till twelve o'clock, when the observers retired. The ship was at this time within the tropic of Capricorn.

In the course of his second voyage, Captain Cook remarks, that on February 17, 1773, "a beautiful phenomenon was observed in the heavens; it consisted of long colours of a clear white light, shooting up from the horizon to the eastward, almost to the zenith, and spreading gradually over the whole southern part of the sky. These columns even sometimes bent sideways at their upper extremity; and though in most respects similar to the northern lights (*Aurora Borealis* of our hemisphere,) yet differed from them in being always of a whitish colour; whereas ours assume various tints, especially those of a fiery and purple hue. The stars were sometimes hid by, and sometimes faintly to be seen through the substance of these southern lights, *Aurora Australis*. The sky was generally clear when they appeared, and the air sharp and cold, the thermometer standing at the freezing

point: the ship being then in 58° south *." Forster speaks of the same phenomenon, as well as six others, on different nights, as February 19, 20, 21, and 26, March 15 and 20 †.

Dalton conceives, and it is the common hypothesis of the day, that the apparent beams of the aurora are the projections of cylindrical portions of a magnetic fluid, which are actually parallel to the dipping needle, and hence seem to converge to the magnetic pole; and that the light is produced by the transmission of electricity through them, which somewhat disturbs their magnetic properties. The arches are always perpendicular to the magnetic meridian; and being more permanent in their form, afford an opportunity of determining the height, which from one observation, on a base of 22 miles, Dalton calculated to be 150 miles.

This calculation is almost a mean between the computations of other observers: for while Cavendish states it at from 52 to 71 miles, Cramer advances it to 160 leagues, and Eames to not less than 200 leagues. Cavendish, however, admits that the nature of the light may make the appearance different in different places, and renders distant observations fallacious.

Eames supposes the aurora to be derived from the sun's atmosphere, extending in some directions beyond the earth's orbit; and attributes the nebulæ of stars and the tails of comets to a similar substance.

Van Swinden observes that the variation of the magnetic needle increases when the aurora borealis is approaching ‡.

Winn remarks, that the aurora is generally followed the day after by a stream from the south or south-west §.

Blagden and Gmelin offer several testimonies of a rustling noise that occasionally accompanied it ||.

EDITOR.

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* Second Voyage, I. 53.

† Observations in a Voyage round the World, p. 120.

‡ Petr. Acad. 1783.

§ Phil. Trans. 1774.

|| Id. 1781.

SECTION II.

Account of surprising Lights in the Air, March 6, 1716; with an attempt to explain their principal Phænomena.

By Edmund Halley, J. V. D. Savilian Professor of Geometry, Oxon, and Secretary to the Royal Society.

On Tuesday, March 6, O. S. 1716, the afternoon having been very serene and calm, and somewhat warmer than ordinary, about seven o'clock, out of what seemed a dusky cloud, in the N. E. parts of the heaven, and scarcely ten degree high, the edges of which were tinged with a reddish yellow, as if the moon had been hid behind it, there arose very long luminous rays or streaks, perpendicular to the horizon, some of which seemed nearly to ascend to the zenith. Presently after, that reddish cloud was swiftly propagated along the northern horizon, into the N. W. and still farther westerly; and immediately sent forth its rays after the same manner from all parts, now here, now there, observing no rule or order in their rising. Many of these rays seeming to concur near the zenith, formed there a corona, or image, which drew the attention of all spectators, who according to their several conceptions made very different resemblances of it; but by which compared together, those that saw it not may well comprehend after what manner it appeared. All agree that this spectrum lasted only a few minutes, and showed itself variously tinged with colours, yellow, red, and a dusky green; nor did it keep in the same place; for when first it began to appear, it was seen a little to the northward of the zenith; but gradually declining toward the south, the long striæ of light, which arose from all parts of the northern semi-circle of the horizon, seemed to meet together, not much above the head of Castor, or the northern Twin, and there soon disappeared.

After the first impetus of this ascending vapour was over, the corona we have been describing appeared no more; but still, without any order as to the time, or place, or size, luminous radii like the former continued to arise perpendicularly. Nor did they proceed as at first, out of a cloud, but oftener would emerge at once out of the pure sky, which was at that time more than ordinary se-

rene and still. Nor were they all of the same form. Most of them seemed to end in a point upwards, like erect cones; others like truncated cones or cylinders, so much resembled the long tails of comets, that at first sight they might well be taken for such. Again, some of these rays would continue visible for several minutes; when others, and those the much greater part, just shewed themselves and died away. Some seemed to have little motion, and to stand as it were fixed among the stars, while others with a very perceptible translation moved from east to west under the pole, contrary to the motion of the heavens; by which means they would sometimes seem to run together, and at other times to fly one another, affording a surprising spectacle to the beholders.

After this sight had continued about an hour and a half, the beams began to rise much fewer in number, and not near so high, and gradually that diffused light, which had illustrated the northern parts of the hemisphere, seemed to subside, and settling on the horizon, formed the resemblance of a very bright crepusculum. On the first information of the thing, I immediately ran to the windows, which happened to look to the south and south-west quarter; and soon perceived, that though the sky was very clear, yet it was tinged with a strange sort of light; so that the smaller stars were scarcely to be seen, and much as it is when the moon of four days old appears after twilight. We perceived a very thin vapour pass before us, which arose from the precise east part of the horizon, ascending obliquely, so as to leave the zenith about fifteen or twenty degrees to the northward. But the swiftness with which it proceeded was scarcely to be believed, seeming not inferior to that of lightning; and exhibiting as it passed on a sort of momentaneous nubecula, which discovered itself by a very diluted and faint whiteness; and was no sooner formed, but before the eye could well take it, it was gone, and left no signs behind it. Nor was this a single appearance; but for several minutes about six or seven times in a minute, it was again and again repeated; these waves of vapour, if I may so call it, regularly succeeding one another, and nearly at equal intervals; all of them in their ascent producing a like transient nubecula.

By this particular we were first assured, that the vapour we saw, whatever it was, became conspicuous by its own proper light, without help of the sun's beams; for these nubecula did not disco-

ѧer themselves in any other part of their passage, but only between the south-east and south, where being opposite to the sun they were deepest immersed in the cone of the earth's shadow, nor were they visible before or after. Whereas the contrary must have happened, had they borrowed their light from the sun.

A little after ten o'clock, we found on the western side, viz. between the W. and N. W. the representation of a very bright twilight, contiguous to the horizon; out of which there arose very long beams of light, not exactly erect toward the vortex, but something declining to the south, which ascending by a quick and undulating motion to a considerable height, vanished in a little time; while others, though at uncertain intervals, supplied their place. But at the same time, through all the rest of the northern horizon, viz. from the north-west to the true east, there did not appear any sight of light to arise from, or join to, the horizon; but on the contrary, what appeared to be an exceedingly black and dismal cloud seemed to hang over all that part of it. Yet it was no cloud, but only the serene sky more than ordinary pure and limpid, so that the bright stars shone clearly in it, and particularly Cauda Cygni then very low in the north; the great blackness manifestly proceeding from the neighbourhood of the light which was collected above it. For the light had now put on a form quite different from all that we have hitherto described, and had fashioned itself into the shape of two laminæ or streaks, lying in a position parallel to the horizon, whose edges were but ill terminated. They extended themselves from the N. by E. to the north-east, and were much about a degree broad; the undermost about eight or nine degrees high, and the other about four or five degrees over it; these kept their places for a long time, and made the sky so light, that I believe a man might easily have read an ordinary print by it.

While we stood astonished at this surprising sight, and expecting what was further to come, the northern end of the upper lamina by degrees bent downwards, and at length closed with the end of the other that was under it, so as to shut up on the north side an intermediate space, which still continued open to the east. Not long after this, in the said included space, we saw a great number of small columns or whitish streaks to appear suddenly, erect, to the horizon, and reaching from one lamina to the other; which instantly disappearing, were too quick for the eye, so that we could not

judge whether they arose from the under or fell from the upper, but by their sudden alterations they made such an appearance as might well be taken to resemble the conflicts of men in battle.

And much about the same time, to increase our wonder, there began on a sudden to appear, low under the pole and very near due north, three or four lucid areas like clouds, discovering themselves, in the pure but very black sky, by their yellowish light. These, as they broke out at once, so after they had continued a few minutes, disappeared as quick as if a curtain had been drawn over them. They were of no determined figure, but both in shape and size might properly be compared to small clouds illuminated by the full moon, but brighter.

Not long after this, from above the aforesaid two laminæ, there arose a very great pyramidical figure, like a spear, sharp at the top, whose sides were inclined to each other with an angle of about four or five degrees, and which seemed to reach up to the zenith, or beyond it. This was carried with an equable and not very slow motion, from the N. E. where it arose, into the N. W. where it disappeared, still keeping a perpendicular situation, or very near it; and passing successively over all the stars of the Little Bear, did not efface the smaller ones in the tail, which are but of the fifth magnitude; such was the extreme rarity and perspicuity of the matter it consisted of.

This single beam was so far remarkable above all those that for a great while before had preceded it, or that followed it, that if its situation among the circumpolar stars had at the same instant been accurately noted, for example, at London and Oxford, whose difference of longitude is well known, we might be enabled with some certainty to pronounce, by its *diversitas aspectû*, concerning its distance and height; which was doubtless very great, though as yet we can no wise determine them. But as this phenomenon found all those that are skilled in the observation of the heavens unprepared, and unacquainted with what was to be expected; so it left them all surprised and astonished at its novelty. When therefore for the future any such thing shall happen, all those that are curious in astronomical matters, are hereby admonished and entreated to set their clocks to the apparent time at London; for example, by allowing so many minutes as is the difference of me-

ridians, and then to note at the end of every half hour precisely, the exact situation of what at that time appears remarkable in the sky, and particularly the azimuths of those very tall pyramids so eminent above the rest, and therefore likely to be seen farthest; that by comparing those observations taken at the same moment in distant places, the difference of their azimuths may serve to determine how far those pyramids are from us.

It being now past 11 o'clock, and nothing new offering itself to our view, but repeated phases of the same spectacle, we thought it no longer worth while to bear the chill of the night air *sub dio.* Therefore returning to my house, I made haste to my upper windows, which conveniently enough look to the N. E. parts of heaven, and soon found that the two laminæ or streaks parallel to the horizon, of which we have been speaking, had now wholly disappeared: and the whole spectacle reduced itself to the resemblance of a very bright crepusculum, settling on the northern horizon, so as to be brightest and highest under the pole itself, from whence it spread both ways, into the N. E. and N. W. Under this, in the middle of it, there appeared a very black space, as it were the segment of a lesser circle of the sphere cut off by the horizon. It seemed to the eye like a dark cloud, but was not so; for by the telescope the small stars appeared through it more clearly than usual, considering how low they were; and on this as a basis our *lumen auroriforme* rested, which was a segment of a ring or zone of the sphere, intercepted between two parallel lesser circles, cut off likewise by the horizon; or, if you please, the segment of a very broad iris, but of one uniform colour, viz. a flame colour inclining to yellow, its centre being about forty degrees below the horizon. And above this there were seen some rudiments of a much larger segment, with an interval of dark sky between; but this was so exceedingly faint and uncertain, that I could make no proper estimate of it.

I was very desirous to have seen how this phænomenon would end, and attended it till near three in the morning, and the rising of the moon; but for above two hours together it had no manner of change in its appearance, nor diminution nor increase of light: only sometimes for very short intervals, as if new fuel had been cast on a fire, the light seemed to undulate and sparkle, not unlike

the rising vaporous smoke out of a great blaze when agitated. But one thing I assured myself of by this attendance and watching, viz. that this iris-like figure by no means owed its origin to the sun's beams; for that about three in the morning, the sun being in the middle between the north and east, our aurora had not followed him, but ended in that very point where he then was; whereas in the true north, which the sun had long passed, the light remained unchanged, and in its full lustre.

Thus far I have attempted to describe what was seen, and am heartily sorry I can say no more as to the first and most surprising part thereof, which however frightful and amazing it might seem to the vulgar beholder, would have been to me a most agreeable and wished-for spectacle; for I then should have contemplated *propriis oculis* all the several sorts of meteors I remember to have hitherto heard or read of. This was the only one I had not as yet seen, and of which I began to despair, since it is certain it has not happened to any remarkable degree in this part of England since I was born: nor is the like recorded in the English annals since the year of our Lord 1574, that is above 140 years since, in the reign of Queen Elizabeth. Then, as we are told by the historians of those times, Cambden and Stow, eye-witnesses of sufficient credit, for two nights successively, viz. on the 14th and 15th of November that year, much the same wonderful phænomena were seen, with almost all the same circumstances as now.

Nor indeed, during that reign, was this so rare a sight as it has been since. For we find in a book entitled, A Description of Meteors, reprinted at London in the year 1654, signed W. F. D. D. that the same thing, which the author there calls Burning Spears, was seen at London on January 30, 1560; and again, by the testimony of Stow, on the 7th of October, 1564. And from foreign authors we learn, that in the year 1575 the same was twice repeated in Brabant, viz. on the 13th of February and 28th of September; and seen and described by Cornelius Gemma, professor of medicine in the university of Lovain, and son of Gemma Frisius the mathematician. In a discourse he wrote on the prodigies of those times, after several ill-boding prognostics, he thus very properly describes the cupola and corona he saw in the Chasma, as he calls it, of February. " A little after," says he, " spears and new flames

arising, the sky seemed to be all on a flame, from the north quite up to the zenith; and at last, the face of the sky was, for a whole hour together, changed into the uncommon form of a dice-box, the blue and white changing alternately, with no less swiftness and vertigious motion than the sun beams do, when reflected from a mirror."

Here it is not a little remarkable, that all these four already mentioned fell exactly on the same age of the moon, viz. about two days after the change.

As to the other of September in the same year 1575, Gemma writes: "The form of the Chasma, of the 28th of September following, immediately after sun-set, was indeed less dreadful, but still more confused and various; for in it were seen a great many bright arches, out of which gradually issued spears, cities with towers and men in battle array; after that, there were excursions of rays every way, waves of clouds and battles; mutually pursued and fled, and wheeling round in a surprising manner." From hence it is manifest that this phenomenon appeared in our neighbourhood three several times, and that with considerable intervals, within the compass of one year; though our English historians have not recorded the two latter; nor did Gemma see that of November, 1574, probably by reason of clouds. After this, in the year 1580, we have the authority of Michael Mœstlin, (himself a good astronomer, and still more famous for having had the honour to be the great Kepler's tutor in the sciences) in his book de Cometa, 1580, that at Baknang, in the country of Wirtemburg in Germany, these chasmata, as he likewise stiles them, were seen by himself no less than seven times within the space of twelve months. The first and most considerable of these, was on the very same day of the month with ours, viz. on Sunday the 6th of March, and was attended with much the same circumstances. And again, the same things were seen in a very extraordinary manner on the 9th of April and 10th of September following: but in a less degree, on the 6th of April, 21st of September, 26th of December, and 16th of February, 1581: the last of which, and that of the 21st of September, must needs have been more considerable than they then appeared, because the moon being near the full, necessarily effaced all the fainter lights. Of all these however no one is mentioned in our annals to have been seen in England, nor in

any other place that I can find; such was the neglect of curious matter in those days.

The next in order that we hear of, was that of the year 1621, on September the 2d. O. S. seen all over France, and is well described by Gassendus in his physics, who gives it the name of aurora borealis. This, though little inferior to what we lately saw, and appearing to the northwards both of Rouen and Paris, is no where said to have been observed in England, over which the light seemed to lie. And since then, for above 80 years, we have no account of any such sight, either at home or abroad: though for above half that time, these Philos. Trans. have been a constant register of all such extraordinary occurrences. The first we find on our books, was one of small continuance, seen in Ireland by Mr. Nave, Nov. 10, 1707; of which see Philos. Trans. No. 320. And in the Miscellanea Berolinensia, published in 1710, we learn that in the same year 1707, both in January 24, and February 18, O. S. something of this kind was seen by M. Olaus Romer, at Copenhagen: and again February 23, the same excellent astronomer observed there such another appearance, but much more considerable; of which yet he only saw the beginning, clouds interposing. But the same was seen that night by Mr. Gottfried Kirch at Berlin, about 200 miles from Copenhagen, and lasted there till past ten at night. To these add another small one of short duration, seen near London, a little before midnight between the 9th and 10th of August, 1708, by the Right Rev. Philip, Lord Bishop of Hereford, and by his lordship communicated to the Royal Society: so that, it seems, in little more than eighteen months this sort of light has been seen in the sky no less than five times, in the years 1707 and 1708.

Hence we may reasonably conclude that the air, or earth, or both, are sometimes, though but seldom and at great intervals, disposed to produce this phenomenon; for though it be probable that many times, when it happens, it may not be observed, as falling out in the day-time, or in cloudy weather, or bright moonshine; yet that it should be so very often seen at some times, and so seldom at others, is what cannot well be accounted for that way. Therefore considering what might be most probably the material cause of these appearances; what first occurred was the vapour of water rarefied exceedingly by subterraneous fire, and tinged with sulphureous steams; which vapour is now generally supposed by

naturalists to be the cause of earthquakes. And as earthquakes happen with great uncertainty, and have been sometimes frequent in places where for many years before and after they have not been felt; so these, which we might be allowed to suppose produced by the irruption of the pent vapour through the pores of the earth, when it is not in sufficient quantity, nor sudden enough to shake its surface, or to open itself a passage by rending it. And as these vapours are suddenly produced by the fall of water, on the nitro-sulphureous fire under ground, they might well be thought to get from thence a tincture which might dispose them to shine in the night, and a tendency contrary to that of gravity; as we find the vapours of gunpowder, when heated *in vacuo*, to shine in the dark, and ascend to the top of the receiver, though exhausted.

Nor should I seek for any other cause than this, if in some of these instances, and particularly this whereof we treat, the appearance had not been seen over a much greater part of the earth's surface than can be thus accounted for. It having in this last been visible from the west side of Ireland to the confines of Russia and Poland on the east, nor do we yet know its limits on that side, extending over at least thirty degrees of longitude; and in latitude, from about fifty degrees over almost all the north of Europe, and in all places exhibiting at the same time the same wondrous circumstances. Now this is a space much too wide to be shaken at any one time by the greatest of earthquakes, or to be affected by the perspiration of that vapour, which being included and wanting vent, might have occasioned the earth to tremble. Nor can we this way account for that remarkable particular attending these lights, of being always seen on the north-side of the horizon, and never to the south.

Therefore laying aside all hopes of being able to explain these things by the ordinary vapours or exhalations of the earth or waters, we must have recourse to other sorts of effluvia of a much more subtile nature, and which perhaps may seem more adapted to bring about those wonderful and surprisingly quick motions we have seen. Such is the magnetical effluvia, whose atoms freely permeate the pores of the most solid bodies, meeting with no obstacle from the interposition of glass or marble, or even gold itself. Some of these, by a perpetual efflux, arise from the parts near the poles of the magnet, whilst others of the like kind of atoms, but

with a contrary tendency, enter in at the same parts of the stone, through which they freely pass; and by a kind of circulation surround it on all sides, as with an atmosphere, to the distance of some diameters of the body. This thing Descartes has endeavoured to explain (Princip. Philosoph. lib. iv.) by the hypothesis of the circulation of certain screwed or striate particles, adapted to the pores they are to enter.

But without inquiring how sufficient the Cartesian hypothesis may be for answering the several phænomena of the magnet; that the fact may be the better comprehended, we shall endeavour to exhibit the manner of the circulation of the atoms concerned therein, as they are exposed to view, by placing the poles of a terrella or spherical magnet on a plain, as the globe on the horizon of a right sphere; then strewing fine steel dust, or filings, very thin on the plain all round it, the particles of steel, on a continued gentle knocking on the underside of the plain, will by degrees conform themselves to the figures in which the circulation is performed. Hence it may appear how this exceedingly subtile matter revolves; and particularly how it permeats the magnet with more force and in greater quantity in the circumpolar parts, entered into it on the one side, and emerging from it on the other, under the same oblique angles: while in the middle zone, near the magnet's equator, very few, if any, of these particles impinge, and those very obliquely.

Now by many and very evident arguments, it appears that our globe of earth is no other than one great magnet; or if I may be allowed to alledge an invention of my own, rather two; the one including the other, as the shell includes the kernel; for so and not otherwise we may explain the changes of the variation of the magnetical needle: but to our present purpose the result is the same. It suffices, that we may suppose the same sort of circulation of such an exceedingly fine matter to be perpetually performed in the earth, as we observe in the terrella; which subtile matter freely pervading the pores of the earth, and entering into it near its southern pole, may pass out again into the ether, at the same distance from the northern, and with a like force; its direction being still more and more oblique, as the distance from the poles is greater. To this we beg leave to suppose, that this subtile matter, no otherwise discovering itself but by its effects on the magnetic needle, wholly

imperceptible, and at other times invisible, may now and then, by the concourse of several causes very rarely coincident, and to us as yet unknown, be capable of producing a small degree of light; perhaps from the greater density of the matter, or the greater velocity of its motion: after the same manner as we see the effluvia of electric bodies, by a strong and quick friction, emit light in the dark: to which sort of light this seems to have a great affinity.

This being allowed, I think we may readily assign a cause for several of the strange appearances we have been treating of, and for some of the most difficult to account for otherwise; as, why these lights are rarely seen any where else but in the north, and never, that we hear of, near the equator: as also why they are more frequently seen in Iceland and Greenland, than in Norway, though nearer the pole of the world. For the magnetical poles, in this age, are to the westward of our meridian, and more so of that of Norway, and not far from Greenland; as appears by the variation of the needle this year, 1716, observed, full 12 degrees at London to the west.

The erect position of the luminous beams or striæ so often repeated that night, was occasioned by the rising of the vapour or lucid matter nearly perpendicular to the earth's surface. For any line erected perpendicularly on the surface of the globe, will appear erect to the horizon of an eye placed any where in the same spherical superficies; as Euclid demonstrates in a plane, that any line erected at right angles to it, will appear to be perpendicular to that plane from any point of it. That it should be so in the sphere is a very pretty proposition, not very obvious, but demonstrated from Prop. 5, Lib. i, Theodosii Sphæric. For by it all lines erected on the surface pass through the centre, where meeting with those from the eye, they form the planes of vertical circles to it. And by the converse hereof, it is evident that this luminous matter arose nearly perpendicular to the earth's surface, because it appeared in this erect position. And whereas in this appearance (and perhaps in all others of the kind) those beams which arose near the east and west, were farthest from the perpendicular on both sides, inclining towards the south, while those in the north were directly upright: the cause of which may well be explained by the obliquity of the magnetical curves,

making still obtuser angles with the meridians of the terella, as they are farther from its poles.

Hence also it is manifest how that wonderful corona, that was seen to the southward of the vertex, in the beginning of the night, and so very remarkable for its tremulous and vibrating light, was produced; viz. by the concourse of many of those beams rising very high out of the circumjacent regions, and meeting near the zenith: their effluvia mixing and interfering with one another, and so occasioning a much stronger but uncertain wavering light. And since it is agreed by all our accounts that this corona was tinged with various colours, it is more than probable that these vapours were carried up to such a height, as to emerge out of the shadow of the earth, and to be illuminated by the direct beams of the sun: whence it might come to pass that this first corona was seen coloured, and much brighter, than what appeared afterwards in some places, where the sight of it was more than once repeated, after the sun was gone down much lower under the horizon. Hence also it will be easily understood, that this corona was not one and the same in all places, but was different in every differing horizon; exactly after the same manner as the rainbow, seen in the same cloud, is not the same bow, but different to every several eye.

Nor is it to be doubted, but the pyramidical figure of these ascending beams is optical: since probably they are parallel-sided, or rather tapering the other way. But by the rules of perspective their sides ought to converge to a point, as we see in pictures the parallel borders of straight walks, and all other lines parallel to the axis of vision, meet as in a centre. Therefore those rays which rose highest above the earth, and were nearest the eye, seemed to terminate in cusps sufficiently acute, and have been for that reason supposed by the vulgar to represent spears. Others seen from afar, and perhaps not rising so high as the former, would terminate as if cut off with plains parallel to the horizon, like truncated cones or cylinders: these have been taken to look like the battlements and towers on the walls of cities, fortified after the ancient manner. While others yet further off, by reason of their great distance, good part of them being intercepted by the interposition of the convexity of the earth, would

only shew their pointed tops, and because of their shortness have been called swords.

Next, the motion of these beams furnishes us with a new, and most evident argument, to prove the diurnal rotation of the earth: though that be a matter which, at present, is generally taken by the learned to be past dispute. For those beams which rose up to a point, and did not presently disappear, but continued for some time, had most of them a sensible motion from east to west, contrary to that of the heavens; the largest and tallest of them, as being nearest, swiftest; and the more remote and shorter, slower. By which means, the one overtaking the other, they would sometimes seem to meet and jostle; and at other times to separate, and fly one another. But this motion was only optical, and occasioned by the eye of the spectator being carried away with the earth into the east; while the exceedingly rare vapour which those beams consisted of, being raised far above the atmosphere, was either wholly left behind, or else followed with but part of its velocity, and therefore could not but seem to recede and move the contrary way. And after the same manner as the stars that go near the zenith, pass over those verticle circles which border on the meridian, much swifter than those stars which are more distant from it; so these luminous rays would seem to recede faster from east to west, as their bases were nearer the eye of the spectator; and *è contra*, slower as they were farther off.

Nor are we to think it strange, if after so great a quantity of luminous vapour had been carried up into the ether, out of the pores of the earth, the cause of its effervescence at length abating, or perhaps the matter consumed, these effluvia should at length subside, and form those two bright luminations which we have described; and, whose edges being turned to us, were capable to emit so much light that we might read by them. I choose to call them luminations, because, though they were but thin, doubtless they spread horizontally over a large tract of the earth's surface. And while this luminous matter dropped down from the upper plate to the under, the many white columns were formed between them by its descent, only visible for the moment of their fall. These, by the swiftness with which they vanished, and their great number, shewing themselves and disappearing without any order,

exhibited a very odd appearance; those on the right seeming sometimes to drive and push those on the left, and *vice versa*.

These are the principal phænomena; of whose causes I should have more willingly and with more certainty given my thoughts, if I had had the good luck to have seen the whole from beginning to end; and to have added my own remarks to the relations of others: and especially if we could by any means have come at their distances. If it shall by any be thought a bold supposition, that I assume the effluvia of the magnetical matter for this purpose, which in certain cases may themselves become luminous, or rather may sometimes carry with them out of the bowels of the earth a sort of atoms proper to produce light in the ether; I answer, that we are not as yet informed of any other kinds of effluvia of terrestrial matter which may serve for our purpose, than those we have here considered, viz. the magnetical atoms, and those of water highly rarefied into vapour. Nor do we find any thing like it in what we see of the celestial bodies, unless it be the effluvia projected out of the bodies of comets to a vast height, and which seem by a *vis centrifuga* to fly with an incredible swiftness, the centres both of the sun and comet, and to go off into tails of a scarcely conceivable length. What may be the constitution of these cometical vapours, we the inhabitants of the earth can know but little, and only that they are evidently excited by the heat of the sun; whereas this meteor, if I may so call it, is seldom seen except in the polar regions of the world, and that most commonly in the winter months. But whatever may be the cause of it, if this be not, I have followed the old axiom of the schools, *Entia non esse temere neque absque necessitate multiplicanda*.

Lastly, I beg leave on this occasion to mention what, near 25 years since, I published in No. 195 of these Transactions, viz. That supposing the earth to be concave, with a less globe included, in order to make that inner globe capable of being inhabited, there might not improbably be contained some luminous medium between the balls, so as to make a perpetual day below. That very great tracts of the etherial space are occupied by such a shining medium, is evident from the instances given in the first paper of this Transaction; and if such a medium should be thus inclosed within us, why may we not be allowed to suppose that some parts

of this lucid substance may, on very rare and extraordinary occasions, transude through and penetrate the cortex of our earth, and being got loose may afford the matter of which this our meteor consists. This seems favoured by one considerable circumstance, viz. that the earth, because of its diurnal rotation, being necessarily of the figure of a flat spheroid, the thickness of the cortex, in the polar parts of the globe, is considerably less than towards the equator; and therefore more likely to give passage to these vapours; whence a reason may be given why these lights are always seen in the north. But I desire to lay no more stress on this conceit than it will bear.

It having been noted that in the years 1575 and 1580, when this appearance was frequent, that it was seen not far from the lines of the two equinoxes; it may be worth while for the curious to bestow some attention on the heavens in the months of September and October next; and in case it should again happen, to endeavour to observe, by the method I have here laid down, what may determine, with some degree of exactness, its distance and height; without which we can scarcely come to any just conclusion.

[*Phil. Trans.* 1716.

SECTION III.

Observations on the Lumen Boreale, or Streaming, Oct. 8, 1726.

By the Rev. W. Derham, F. R. S.

There are two sorts of streamings, which have been noticed; one, by way of explosion from the horizon; the other, by opening and shutting, without shootings up, and swift dartings. Of the latter sort chiefly was that of October 8, 1726, in which, although the streams or spires, or lances, or cones, or whatever else they may be called, were as large and remarkable as in the year 1715-6; yet they exhibited themselves principally by the vaporous matter opening and shutting, as if a curtain had been drawn and withdrawn before them. It began about eight o'clock, and soon streamed all round in the south, east and west, as much, or nearly as much, as in the north; which was a thing not observed before in these phænomena.

These streams, or cones, were mostly pointed, and of different length, so as to make the appearance of flaming spires or pyramids; some again were truncated and reached but half way: some had their points reaching up to the zenith, or near it, where they formed a sort of canopy, or thin cloud, sometimes red, sometimes brownish, sometimes blazing as if on fire, and sometimes emitting streams all round it. This canopy was manifestly formed by the matter carried up by the streaming on all parts of the horizon. This sometimes seemed to ascend with a force, as if impelled by the impetus of some explosive agent below, like that of March 1715-16. This forcible ascent of the streaming matter, gave a motion to the canopy, sometimes a gyration, like that of a whirlwind; which was manifestly caused by the streams striking the outer parts of the canopy. But if it struck the canopy in the middle, all was then in confusion.

These two particulars, namely, the streaming all round, in all points of the horizon; and the canopy in and near the zenith, are what were observed in all parts of England. But in the more southerly parts of Europe, it seems to have been somewhat different, by the accounts from different places.

One thing observed in most places was, that in some part of the greatest streaming, the vapours between the spires, or lances, were of a blood-red colour; which gave those parts of the atmosphere the appearance of blazing lances, and bloody-coloured pillars. There was also a strange commotion among the streams, as if some large cloud, or other body, was moving behind them, and disturbed them. In the northerly and southerly parts the streams were perpendicular to the horizon; but in the intermediate points they seemed to decline more or less one way or other; or rather to incline towards the meridian.

As for the cause of these phænomena, Mr. Derham takes it to be from the same matter, or vapours, which produce earthquakes: and that for these reasons: First, because some of these phænomena have been followed by earthquakes. As that which Stow gives an account of in his Annals, in the year 1574, on Nov. 14; in which he says, " were seen in the air strange impressions of fire and smoke to proceed forth of a black cloud in the north towards the south. That the next night following, the heavens from all parts did seem to burn marvellous ragingly, and over our heads the

flames from the horizon round about rising did meet, and there double and roll one in another, as if it had been in a clear furnace." And after this, he says followed, on the 26th of February, great earthquakes in the cities of York, Worcester, Gloucester, Bristol, Hereford, and in the countries about, which caused the people to run out of their houses, for fear they should have fallen on their heads. In Tewksbury, Breedon, &c. the dishes fell from the cupboards, and the books in men's studies from the shelves, &c.

So this last, in October, was preceded by that fatal earthquake at Palermo in Sicily, and succeeded by one in England, on Tuesday, October 25, following. This it seems was perceived in London, and was very considerable at Dorchester, Weymouth, Portland, Portsmouth, Purbeck, and several other places in Dorsetshire, that it caused the doors to fly open, shook down pewter off the shelves, and was felt in some ships that lay in the harbours.

Another reason is, that some gentlemen viewing this appearance, on the tops of their houses at Little Chelsea, plainly perceived a sulphurous smell in the air. Another thing which concurs with what has been said, is, that several persons heard a hissing, and in some places a crackling noise, in the time of the streaming, like what is reported to be often heard in earthquakes.

[*Id.* 1727.

SECTION IV.

Collection of the Observations of the remarkable Red Lights shewn in the Air, Dec. 5, *or* 16, *N. S. sent from different places to the Royal Society.*

As observed at Naples by the Prince of Cassano, F.R.S.

Dec. 16, 1737, N. S. in the evening, the sun being about 25 degrees below the horizon, a light was observed in the north, as if the air was on fire, and flashing; the intenseness of which gradually increasing, at the 3d hour of the night it spread much westward. Its greatest height was about 65°; for it occupied the whole extent of both the Bears and the polar star; yet at the sides it was not so high; for in some places near the north it rose only to 50°, and it gradually diminished, so as to become insensible at the true horizon.

The abovementioned light at its extremities was unequally jagged, and scattered, and followed the course of the westerly wind; so that for a few hours it spread considerably wider, yet without ever reaching the zenith. About the 6th hour of the night the intenseness of the colour disappeared; some small traces of the inflammation still remaining towards the north-east and the west, which were all vanished at $7\frac{1}{2}$h. of the night.

The inflamed matter, in the greatest part of its extent, gave a free passage to the rays of the stars, even of the 3d and 4th magnitude, situate behind it. About the 4th hour of the night, a very regular arch, of a parabolic figure, was seen to rise gently, to 2° of rectangular elevation, and to 20° of horizontal amplitude. This phenomenon was seen all over Italy, as appears by several accounts of it, though with some disagreement between them.

The most probable opinion as to the cause of this phenomenon, ascribes it to the simple firing of a bituminous and sulphureous matter, on account of its very little specific gravity, raised to the upper parts of the atmosphere, and there, by the clashing of contrary winds, broken, comminuted, and at last set on fire. This opinion has been defended with strong arguments in the Petersburg Commentaries, by Mayer, on occasion of the appearance of a similar phenomenon in those northern countries. And indeed the preceding eruption of Vesuvius, the contrariety of the moving forces, the readiness of the matter to take fire, the unequal intenseness of the light, the streaks, and all the other circumstances observed in this meteor, are plain arguments of a genuine and real ascension. And Wolfius, on the appearance of a phenomenon much like this, which was seen all over Germany, on the 17th of March, 1717, is of opinion, that it should be called imperfect lightning, as being produced by the inflammable matter of lightning.

Observed at Padua, by the Marquis Poleni, F.R.S.

At the time of this meteor, the air was calm, and the barometer was remarkably high.

At $5\frac{1}{4}$h. there appeared near the horizon a blackish zone, with its upper limb of a sky-colour, somewhat obscure. Above this zone was another very luminous, resembling the dawn pretty far advanced. The highest zone was of a red fiery colour. The altitudes of the zones seemed to bear such proportion, that the second

was double the first, and the third triple; and in many places they rose somewhat above the 40th degree of altitude. Eastward they extended to the 55th degree on the horizon, and westward to the 70th.

It is remarkable, that after sun-set on the preceding days, as well as this, there appeared in the west a remarkable redness expanded on each side; and on the ensuing evening, the same bright red colour, appearing near the horizon, deceived the common people into a belief, that a new phenomenon, like the foregoing, was breaking out of the horizon. Near our zenith there appeared some thin lucid clouds, partly of a whitish red, in such a manner, that they seemed as if occasioned by the burning of houses at some distance to the north. Others of this sort had happened before, and some were seen afterwards.

A little after 6, the upper parts began to emit red streamings, or rays, in plenty; but in these the red was now and then intermixed with whitish and darkish colours. In a few seconds after, there issued out from the very equinoctial west, a red and very bright column, which ascended to the third part of the heavens, and a little after, it became curved in the shape of the rainbow.

At half after 8, almost in an instant of time, the bright zone, from the 8th degree west to the 50th east, became more vivid, and rose higher; and above this appeared a new large one, of a red fiery colour, with several successive streamings tending upward, and passing 60 degrees of altitude; the western part had assumed the form of a thin cloud. At twelve, the light of the aurora was nearly extinct, there appearing only a very weak light along the tops of the mountains. Twenty minutes after, there appeared a white brightish beam, at 30° west, and 60° high; but it soon became invisible. In half an hour after, a very weak light remained in the west, near the horizon; which had not been observable, if the brightness of the preceding phenomenon had not invited to continue the observation.

3. *Observed at the Observatory of the Institute of Bononia.*

By Dr. Eustachio Zanotti, Deputy Professor of Astronomy.

The aurora borealis, which was formerly a rare phenomenon, and almost unknown in this climate, is now become very frequent. In Bononia a great number have been observed for some years past.

This time it was so very remarkable, that no one remembers to have ever seen the like. As to its extent, it spread so as to occupy about 140° of the heavens; and, as to its light, it was so vivid, as by it to distinguish houses at a great distance; which seemed of a red colour, which made some people attribute this light to a fire in the neighbourhood.

It continued at times variously increasing and decreasing.

About 8, the aurora formed itself into a concave arch towards the horizon. The polar star was near the top of its convexity, and some stars shone bright in the midst of the light; and among these δ and γ of Ursa major. The concave part was terminated by a basis somewhat dark; which separated the red light of the arch from a white and very bright light that remained within it. The arch, which was 15° broad, was of a deeper colour towards the horizon than towards the pole. The western limit, which was interrupted by clouds, was wider and more irregular than the eastern limit. Fig. 2, pl. 10, exhibits the phenomenon conformable to the description now given.

About 8h. 34′ the red light continued spreading, and made, as it were, a basis of a weaker redness. At this time the aurora appeared unsettled and curious, as in fig. 2. At its eastern limit, the pyramid continued visible, but of a more intense colour towards the north, and from its middle there shot up vertically a streak of light, between a white and a yellow colour. A very dark narrow cloud crossed the whole phenomenon, and went to terminate in the pyramid. At the upper part, a considerable tract of the heavens was enlightened with a very vivid red light, which was interrupted by several streaks or columns of a bright yellowish light. These streamings shot up vertically, and parallel to each other, and the narrow cloud seemed to serve them for a basis. Under the cloud there issued forth two tails of a whitish light, hanging downward on a basis of a weak red, and it seemed as if they kindled and darted the light downward. There was likewise seen a white streak, which passed across these two tails, and extended from one end of the phenomenon to the other, in a position almost parallel to the abovementioned cloud.

At 9, 4m. there now remained but a little reddish light at the north pole. All the rest was collected near the zenith, not extending lower than the star α of Ursa major. In the south, where

the sky was clear, there were seen some of those meteors called falling stars.

Several persons have positively asserted, that, in the evening of the 16th day, they perceived a certain stench in the air, like that which is sometimes occasioned by a fog. The same has been taken notice of at other times, when such phænomena have appeared.

There was a very thin fog in the air not only on the 16th day, but also on the preceding and ensuing days. The mornings of the 17th and 18th, before and a little after sun-rise, the air appeared of an uncommon fiery colour. The evening of the 17th, the crepusculum was of an extraordinary height. Between the north and west, there was seen a very thin red vapour, which lasted almost till night.

4. *Observed at Rome, by S. de Revillas, Math. Prof. & F.R.S.*

These observations are similar to the foregoing.

5. *By Mr. James Short, at Edinburgh.*

We were surprised, on looking out of the windows, about six o'clock, to find the sky as it were, all in a flame; but on further inquiry, it was nothing but the aurora borealis, composed of red light. There was an arch of this red light reached from the west, over the zenith, to the east; the northern border of this light was tinged with somewhat of a blue colour. This aurora did not first form in the north, and after forming an arch there, rise towards the zenith, as they commonly use to do; neither did the light shiver, and by sudden jirks spread itself over the hemisphere, as is common; but gradually and gently stole along the face of the sky, till it had covered the whole hemisphere; which alarmed the vulgar, and was indeed a strange sight. A great circle of this light came from the west to the zenith, which seemed to be the magazine whence all the rest were supplied. It is but about a year since Mr. S. first observed this red light in the aurora borealis, and only then in very small quantities.

6. *At Rosehill, Sussex, by John Fuller, Esq. jun. F.R.S.*

It was a strong and very steady light, nearly of the colour of red ochre. It did not seem to dart or flash at all, but continued going on in a steady course against the wind, which blew fresh from the south-west. It began about north north-west, in form

of a pillar of light, at about 6h. 15m. in the evening; in about ten minutes, a fourth part of it divided from the rest, and never joined again; in ten minutes more it described an arch, but did not join at top; exactly at seven, it formed a bow, and soon after quite disappeared. It was all the while lightest and reddest at the horizon. It gave as much light as a full moon.

At 8, it began exactly north; it was very light then, but not near so light as before: in half an hour it made an arch from east to west, and went quite away to the south, when it ended much with the same appearance as it began in the north, but not quite so red.

SECTION V.

Account of Luminous Arches.

By Mr. William Hey, of Leeds, F. R. S.

While Mr. Hey was at Buxton, in March, 1774, about half-past eight he saw a luminous arch, which appeared very beautiful in the atmosphere. Its colour was white, inclining to the yellow; its breadth in the crown apparently equal to that of the rainbow. As it approached the horizon, each leg of the arch became gradually broader. It was stationary while he viewed it, and free from any sensible corruscations. Its direction seemed to be from about the N. E. to the S.W. at least its eastern leg was inclined to the north, and its western to the south. Its crown, or most elevated part, was not far from the zenith. The evening was clear, and the stars appeared bright. It continued about half an hour after it was first observed by the company.

In October, 1775, he saw a similar arch at Leeds, of the same colour, breadth, and position. It began to disappear in five or six minutes after he had discovered it, without changing its situation. The manner in which it vanished was quite irregular; large patches in different parts, and of different dimensions, ceasing to be luminous, till the whole had disappeared. The evening was rather cloudy.

In the evening of March 21, 1783, between eight and nine o'clock, Mr. H. observed something like a bright cloud in the eastern part of the hemisphere, and also a similar appearance in the opposite part of the heavens. These luminous parts, which appear-

ed in the eastern and western parts of the horizon, were connected by an arch of a fainter light.

It reached the horizon in the W.S.W. point. In its course it passed about 12° to the south of the zenith. Its breadth was about 9 or 10°. It remained visible about ten or twelve minutes after he first discovered it, and then vanished gradually and irregularly. He observed no corruscations, nor any motion in this arch. A few minutes after another, and still more beautiful, arch made its appearance. It arose a point or two nearer the N.E. than the former had done. Its southern edge passed up a little to the north of the tail of the Great Bear, which was then in a vertical position. Its northern edge appeared at first a little to the south of the polar star; but, during the continuance of the phenomenon, it gradually receded about 10° to the south. The arch descended about the W.N.W.; but neither the eastern nor western extremities reached the horizon; each of them ending in a point gradually formed a little above the horizon. This arch might be about 10 or 12° at its vertex. It continued visible for half an hour; and though he could not discover any corruscations, or quick motion, in any part, yet the different portions of it were perpetually varying in the density of their light, and the whole arch, or at least its vertex, made a slow and equitable motion towards the south. Where the light was the most dense, the smaller stars were rendered invisible by the arch, but stars of the second magnitude were not totally eclipsed by it. This arch disappeared, as the former, by patches; the light gradually becoming less intense. The colour of both these arches was white. Before the latter arch had entirely disappeared, a small one, not quite so broad as the rainbow, arose from its eastern leg, and ascending in a curvilineal direction to the polar star, terminated there. Its light was more faint than that of the other two arches; and it considered visible about a quarter of an hour. The evening was very fine when he saw these beautiful phænomena; the stars were bright, and there was not a cloud to be seen except in the horizon. There was a steady light in the north, without the least corruscation, extending from the N.E. to N.W. The wind blew from the N.E.

March 26, about the same time in the evening, Mr. H. was entertained with a similar appearance. He first observed two or

three columns of aurora borealis shooting upwards in the north; and in a short time after a complete arch, like those already described, though somewhat different in its position. It arose between the E. and N. and N. E. points, passed obliquely to the south below Arcturus, and descended in the west through Orion, having almost the same direction through that constellation which the equator has. Its light was the most faint about the vertex of the arch. Its most dense parts were continually varying in the intensity of their light. The larger stars were visible through its densest parts. It varied its position, and it continued visible about half an hour; but there was nothing which could be called a shooting, or quick corruscation. There was a steady northern light all the evening, or at least till the arch had disappeared.

The grandest specimen of this phenomenon which Mr. H. had seen, appeared on the 12th of April, between nine and ten in the evening. He perceived a broad arch of a bright pale yellow, arising between Arcturus and Lyra, about the right leg of Hercules, and passing considerably to the south of the zenith, its northern border being a little south of Pollux, and descending to the horizon near Orion, which was then setting. This arch seemed to be about 15° in breadth, and was of such a varied density, that it appeared to consist of small columns of light, which had a sensible motion. After about ten minutes he saw innumerable bright corruscations shooting out at right angles from its northern edge, which was concave, and elongating themselves more and more till they had nearly reached the northern horizon. As they descended, their extremities were tipped with an elegant crimson, such as is produced by the electric spark in an exhausted tube. After some time this aurora borealis ceased from shooting, and formed a range of beautiful yellow clouds, extending horizontally about a quarter of a circle. The greatest part of the aurora borealis which darted from this arch towards the north, as well as the cloud-like and more stationary aurora, were so dense that they hid the stars from view. The moon was eleven days old, and shone bright during this scene, but did not eclipse the brightness of these corruscations. The wind was at north, or a little inclined to the east.

The last phenomenon of this kind which Mr. H. saw, was on the 26th of April. About a quarter before ten in the evening, he

observed in the W. a luminous appearance, of the colour of the most common aurora borealis. From this mass or broad column of light issued three luminous arches, each of which made a different angle with the horizon. That nearest to the south seemed to arise at right angles with the horizon: while that nearest to the north made the smallest angle, and passed towards the N. E. through the constellation Auriga, having Capella close to its upper edge. He had not viewed them many minutes when they were rendered invisible by a general blaze of aurora borealis, which possessed the space just before occupied by these arches. He was soon satisfied that where the aurora borealis was dense, it entirely hid from view the stars of the second magnitude. He observed this particularly with respect to the star β in the left shoulder of Auriga. But the corruscations were never so dense as to render Capella invisible. The wind was between the N. and N. E. this evening.

After comparing the phenomena above described with each other, and with those observed by Mr. Cavallo, in London; by Mr. Swinton, at Oxford; by Dr. Huxham, at Plymouth; and by Mr. Sparshal, at Wells, in Norfolk; Mr. H. cannot entertain a doubt, that these arches had all the same origin; and that they ought to be considered as a species of that kind of meteor called aurora borealis.

[*Phil. Trans. Abr.* Vol. xvi. year 1790.

CHAP. XLVI.

BLAZING BALLS AND BURNING STONES.

SECTION I.

General Remarks.

THERE is a very extraordinary class of atmospheric bodies, usually known by the name of fiery or luminous meteors, which yet remains to be described, and which has never hitherto been satisfactorily accounted for. They are of all sizes, from a small shooting star of the fifth magnitude, to a cone or cylinder of two or three miles in diameter. They differ in consistency as much as in dimensions, and in colour as much as in either. They are sometimes a subtile, luminous, and pellucid vapour; sometimes a compact ball or globe, as though the material of which they are formed, were more condensed and concentrated. And not unfrequently they have been found to consist of both, and consequently to assume a comet-like appearance, with a nucleus or compact substance in the centre or towards the centre, and a long thin pellucid luminous main, or tail, sweeping on each side. They are sometimes of a pale white light; at others of a deep igneous crimson; and occasionally iridescent and vibratory. The rarer meteors appear frequently to vanish all of a sudden, as though abruptly dissolved or extinguished in the atmospheric medium; their flight is accompanied with a hissing sound, and their disappearance with an explosion. And the most compact of them, or the nuclei of those that are rarer have often descended to the surface of the earth, and with a force sufficient to bury them many feet under the soil; generally exhibiting marks of imperfect fusion and considerable heat. The substance, in these cases, is for the most part metalline; but the ore of which they consist is no where to be met with, in the same constituent proportions, in the bowels of the earth. Under this form the projected masses are denominated meteoric stones or aërolites.

Yet, however these extraordinary bodies may differ in colour, shape, dimensions, or consistency, they seem to agree with great exactness in their transient appearance, velocity, and elevation, when first discovered. It is seldom they have been capable of being traced longer than from a single moment to two or three minutes; their height has been pretty fairly and concurrently calculated at from fifty to sixty miles above the surface of the earth; and their velocity, from similar calculations, at from twenty to thirty miles in a second; consequently in the lowest computation exhibiting a rapidity more than ninety times that of sound, and nearly approaching to that of the earth in her annual orbit.

Dr. Halley calculated that the meteor seen throughout England in 1718-19 (as the reader will find in his own very instructing description in the subjoined section) must have been sixty miles high, and have passed over three hundred geographical miles in a minute. It exploded with a great report.

Lerry computed that the extensive meteor which appeared to have originated over the coasts of England, in 1770, was from the first more than eighteen leagues high; and described more than sixty leagues in ten seconds.

The prodigious meteor that appeared nearly in the same direction, in 1783, was calculated by Dr. Blagdon (as we shall perceive presently) to have formed at a height of fifty miles; to have been about two miles in length; and to have moved at the rate of about twenty miles in a second. It rushed with a hissing noise, and exploded with a report. Mr. Cavallo computed that at the time of the explosion it was $56\frac{1}{2}$ miles high, 1070 yards in diameter, and its path immediately over Lincolnshire.

Amidst the numerous hypothesis that have been successively advanced, to account for these extraordinary phænomena, and we may add, as successively abandoned, we shall content ourselves with enumerating the following, as those which have possessed the greatest number of advocates.

1. It was contended by Sir J. Pringle, and various other philosophers, that they are revolving bodies, or a kind of terrestrial comets.

2. Dr. Halley conjectured them to consist of combustible vapours, accumulated and formed into concrete bodies on the outskirts, or extreme regions of the atmosphere, and to be suddenly

set on fire by some unknown cause: and this opinion has since been maintained, with little difference, by Sir W. Hamilton and Dr. King.

3. Dr. Blagdon regarded them as altogether electrical phænomena.

4. M. Izarn believed them to consist of volcanic materials, propelled into the atmosphere in the course of explosions of great violence.

5. M. Chladni threw out the hypothesis that they consist of substances existing exterior to the atmosphere of the earth, and other planets, which have never incorporated with them, and are found loose in the vast ocean of space; combined and inflamed by causes unknown to us.

6. The latest, and, at this moment, the most favourite hypothesis, is that the whole, or at least the more compact division of them, consists of materials thrown from immense volcanos in the moon, concerning which we shall speak more at large in a subsequent section. This idea was first started by M. Olbers, in 1795, (Zach's Mon. Corr. vii. 148, as also Phil. Mag. xv. 289.) and has since been very plausibly supported by M. Laplace.

This last hypothesis does not, however, very well apply to the smaller and less substantial meteors of shooting stars: and hence the philosophers who advocate it endeavour to derive these latter phænomena from some other cause, as electricity, or terrestrial exhalations: and observe in support of the distinction they find it necessary to make, that shooting stars must be of a different nature from fire-balls, since they sometimes appear to ascend as well as to fall: an observation that has especially been dwelt upon by Benzenberg and Chladni.

[EDITOR.

SECTION II.

Account of several extraordinary Meteors, or Lights in the Sky.

By Dr. Edmund Halley, F.R.S.

The theory of the air seems now to be perfectly well understood, and its different densities at all altitudes, both by reason and experiment, are sufficiently defined; for, supposing the same air to

occupy spaces reciprocally proportional to the quantity of the superior or incumbent air, I have elsewhere proved, that at forty miles high the air is rarer than at the surface of the earth about 3000 times; and that the utmost height of the atmosphere, which reflects light in the crepusculum, is not fully forty-five miles. Notwithstanding which, it is still manifest, that some sort of vapours, and those in no small quantity, rise nearly to that height. An instance of this may be given in the great light the society had an account of (vide Trans. Sept. 1676) from Dr. Wallis, which was seen in very distant counties almost over all the south part of England; of which, though the Doctor could not get so particular an account as was requisite to determine its height, yet from the distant places it was seen in, it could not but be a great many miles high.

So likewise that meteor which was seen in 1708, on the 31st of July, between nine and ten o'clock at night, was evidently between forty and fifty miles perpendicularly high, and as near as I can gather, over Sheerness and the Buoy on the Nore; for it was seen at London moving horizontally from E. by N. to E. by S. at least fifty degrees high, and at Redgrave in Suffolk, on the Yarmouth road, about twenty miles from the east coast of England, and at least forty miles to the eastward of London: it appeared a little to the westward of the south, suppose S. by W. and was seen about thirty degrees high, sliding obliquely downwards. I was shown in both places its situation, but could wish some person skilled in astronomical matters had seen it, that we might pronounce concerning its height with more certainty; yet, as it is, we may securely conclude, that it was not many miles more westerly than Redgrave, which, as I said before, is above forty miles more easterly than London. Suppose it therefore, where perpendicular, to have been thirty-five miles east from London, and by the altitude it appeared at in London, viz. at fifty degrees, its tangent will be forty-two miles, for the height of the meteor above the surface of the earth, which also is rather of the least, because the altitude of the place shown me, is rather more than fifty degrees; and the like may be concluded from the altitude it appeared in at Redgrave, near seventy miles distant. Though at this great distance, it appeared to move with an amazing velocity, darting, in a very few seconds of time, for about twelve degrees of a great circle from north to south, being very bright at its first appearance; and it died

away at the end of its course, leaving for some time a pale whiteness in the place, with some remains of it in the track where it had gone; but no hissing sound as it passed, or explosion, was heard.

It may deserve the honourable Society's thoughts, how so great a quantity of vapour should be raised to the very top of the atmosphere, and there collected, so as upon its ascension, or otherwise illumination, to give a light to a circle of above 100 miles diameter, not much inferior to the light of the moon; so as one might see to take a pin from the ground in the otherwise dark night. It is hard to conceive what sort of exhalations should rise from the earth, either by the action of the sun or subterranean heat, so as to surmount the extreme cold and rareness of the air in those upper regions: but the fact is indisputable, and therefore requires a solution.

Like to this, but much more considerable, was that famous meteor which was seen to pass over Italy, on the 21st of March, O. S. Anno 1676, about an hour and three quarters after sun-set, which happened to be observed, and was well considered, by the famous professor of mathematics in Bononia, Geminian Montanari, as may be seen in his Italian treatise about it, soon after published at Bononia. He observes that at Bononia its greatest altitude in the S. S. E. was thirty-eight degrees, and at Siena fifty-eight to the N. N. W.; that its course, by the concurrence of all the observers, was from E. N. E. to W. S. W. that it came over the Adriatic Sea as from Dalmatia: that it crossed over all Italy, being nearly vertical to Rimini and Savigniano on the one side, and to Leghorn on the other: that its perpendicular altitude was at least thirty-eight miles: that in all places near this course, it was heard to make a hissing noise as it passed, like that of artificial fire-works: that having passed over Leghorn, it went off to sea towards Corsica; and lastly, that at Leghorn it was heard to give a very loud report like a great cannon: immediately after which, another sort of sound was heard, like the rattling of a great cart running over stones, which continued about the time of a credo.

He concludes, from the apparent velocity it went with at Bononia, at above fifty miles distance, that it could not be less swift than 160 miles in a minute of time, which is above ten times as swift as the diurnal rotation of the earth under the equinoctial, and not many times less than that with which the annual motion of the earth about the sun is performed. To this he adds, its magni-

tude, which appeared at Bononia larger than the moon in one diameter, and above half as large again in the other; which with the given distance of the eye, makes its real less diameter above half a mile, and the other in proportion. This supposed, it cannot be wondered that so great a body moving with such an amazing velocity through the air, though so much rarefied as it is in its upper regions, should occasion so loud a hissing noise, as to be heard at such a distance as it seems this was. But it will be much harder to conceive, how such an impetus could be impressed on this body, which far exceeds that of any cannon ball; and how this impetus should be determined in a direction so nearly parallel to the horizon; and what sort of substance it must be, that could be so impelled and ignited at the same time: there being no volcano, or other spiriculum of subterraneous fire, in the N. E. parts of the world, that we ever yet heard of, from whence it might be projected.

I have much considered this appearance, and think it one of the hardest things to account for, that I have yet met with in the phænomena of meteors; and am induced to think that it must be some collection of matter formed in the æther, as it were by some fortuitous concourse of atoms, and that the earth met with it as it passed along in its orb, then but newly formed, and before it had conceived any impetus of descent towards the sun. For its direction was exactly opposite to that of the earth, which made an angle with the meridian at that time (the sun being in about eleven degrees of Aries) of 67°; that is, its course was from W. S. W. to E. N. E. so that the meteor seemed to move the contrary way. And besides, falling into the power of the earth's gravity, and losing its motion from the opposition of the medium, it seems that it descended towards the earth, and was extinguished in the Tyrrhene Sea, to the W. S. W. of Leghorn. The great report being heard on its first immersion into the water; and the rattling, like the driving a cart over stones, being what succeeded on its quenching; something like which is always observed on quenching a very hot iron in water. These facts being past dispute, I would be glad to have the opinion of the learned on them, and what objection can be reasonably made against the abovesaid hypothesis, which I humbly submit to their censure.

P. S. Since this was written, there has fallen into my hands an account of nearly such another appearance, seen in Germany, in the year 1686, at Leipsic, by the late Mr. Gottfried Kirch, who was for many years a very diligent observer of the heavens, and was perfectly well instructed in astronomical matters. In an Appendix to his Ephemerides for the year 1688, he gives this remarkable account of it. "On the 9th of July, O. S. at half an hour past one in the morning, a fire ball with a tail was observed in $8\frac{1}{2}$ degrees of Aquarius, and 4° north, which continued immoveable for half a quarter of an hour, having a diameter nearly equal to half the moon's diameter. At first, its light was so great that we could see to read by it: after which, it gradually vanished in its place. This phenomenon was observed at the same time in several other places; especially at Schlaitza, a town distant from Dantzic eleven German miles towards the south, its altitude being about 6° above the southern horizon."

At the time of this appearance the sun was in $26\frac{1}{2}$° of Cancer, and by the given place of the meteor, it is plain, it was seen about $\frac{3}{4}$ of an hour past the meridian, or in S. by W. and by its declination it could not be above 24° high at Leipsic, though the same, at Schlaize, was about 60° high: the angle therefore at the meteor was about 36°. Whence, by an easy calculus, it will be found, that the same was not less than sixteen German miles distant in a right line from Leipsic, and above $6\frac{1}{2}$ such miles perpendicular above the horizon, that is at least thirty English miles high in the air. And though the observer says of it, immotus perstitit per semi-quadrantem horæ, it is not to be understood that it keeps its place like a fixed star, all the time of its appearance; but that it had no very remarkable progressive motion. For he himself has, at the end of the said Ephemerides given a figure of it, which he has marked fig. D. whence it appears that it darted downwards obliquely to the right-hand, and where it ended, left two globules or nodes, not visible but by an optic tube (a telescope.)

The same Mr. Gottfried Kirch, in the begining of a German treatice of his, concerning the great comet which appeared in the year 1680, entitled Newe Himmels Zeitung, printed at Nurenburg, anno 1681, gives an account of such another luminous meteor, seen likewise at Leipsic, on the 22d of May, 1680, O. S. about three in the

morning; which though he himself saw not, was yet there observed by several persons, who made various reports of it; but the more intelligent agreed that it was seen descending in the north, and left behind it a long white streak where it had passed. At the same time, at Haarburg, the like appearance was seen in the N. E. or rather N. N. E.; as also at Hamburg, Lubec, and Stralsund, all which are about forty German miles from Leipsic: but in all these places, by persons unacquainted with the manner of properly describing things of this kind. So that all we can conclude from it is, that this meteor was exceedingly high above the earth, as well as the former.

All the circumstances of these phænomena agree with what was seen in England, in 1708; but it commonly so happens, that these contingent appearances escape the eyes of those that are best qualified to give a good account of them. It is plain, however, that this sort of luminous vapour is not exceedingly seldom thus collected; and when the like shall again happen, the curious are entreated to take more notice of them than has been hitherto done, that we may be enabled the better to account for the surprising appearances of this sort of meteor.

[*Phil. Trans.* 1714.

SECTION III.

Extraordinary Blazing Meteor, seen all over England, March 19, 1718-19.

By the same.

This wonderful luminous meteor, which was seen in the heavens on the 19th of March, as it was matter of surprise and astonishment to the vulgar spectator, so it afforded no less subject of inquiry and entertainment to the speculative and curious in physical matters, some of its phænomena being exceedingly hard to account for, according to the notions hitherto received by our naturalists; such are the very great height thereof above the earth, the vast quantity of its matter, the extreme velocity with which it moved, and the prodigious explosions heard at so great a distance, whose sound, attended with a very sensible tremor of the subject air,

was certainly propagated through a medium extremely rare, and next to a vacuum.

In No. 341 of these Transactions, I have collected what I could find of such meteors; and since, turning over the Ephemerides of Kepler, I accidentally hit upon another, prior to all those there described, and which was seen all over Germany, Nov. 7, O. S. 1623, and in Austria also was heard to burst with an explosion like thunder. Yet neither this nor any of the other hitherto described, seem to come up in any circumstance to this late appearance; of which I am in hopes to give a satisfactory account, being enabled thereto by the numerous accounts communicated to the Royal Society from most parts of the kingdom. Some of the most perfect descriptions we have received are the following.

First, our very worthy vice president, Sir Hans Sloane, being abroad at that time, happened to have his eyes turned towards it, at its very first erruption; of which he gave the following account: that walking in the streets in London, at about a quarter after eight at night, he was surprised to see a sudden great light, far exceeding that of the moon, which shone very bright. He turned to the westward, where the light was, which he apprehended at first to be artificial fire works, or rockets. The first place he observed it in, was about the Pleiades northerly; whence it moved after the manner of a falling star, but more slowly, in a seeming direct line, descending a little beyond and below the stars in Orion's Belt, then in the S. W. The long stream appeared to be branched about the middle, and the meteor in its way turned pear-fashioned, or tapering upwards. At the lower end it came at last to be larger and spherical, though it was not so large as the full moon. Its colour was whitish, with an eye of blue, of a most vivid dazzling lustre, which seemed in brightness very nearly to resemble, if not surpass, that of the body of the sun in a clear day. This brightness obliged him to turn his eyes several times from it, as well when it was a stream, as when it was pear fashioned and a globe. It seemed to move in about half a minute, or less, about the length of 20°, and to go out about as much above the horizon. There was left behind it, where it had passed, a track of a cloudy or faint reddish yellow colour, such as red hot iron or glowing coals have, which continued more than a minute, seemed to sparkle, and kept its place without falling. This tract was interrupted, or had a chasm

towards its upper end, at about two-thirds of its length. He did not hear any noise it made; but the place where the globe of light had been, continued for some time after it was extinct, of the same reddish yellow colour with the stream, and at first some sparks seemed to issue from it, such as come from red-hot iron beaten out on an anvil.

All the other accounts of the phenomenon, in London, agree in this, that the splendour was little inferior to that of the sun; that within doors the candles gave no manner of light, and in the streets not only all the stars disappeared, but the moon, then nine days old, and high near the meridian, the sky being very clear, was so far effaced as to be scarcely seen; at least not to cast a shade, even where the beams of the meteor were intercepted by the houses; so that for some few seconds of time, in all respects resembled perfect day.

The time when this happened was generally reckoned at a quarter past eight; but by the more accurate account of the Rev. Mr. Pound, who only saw the light, agreeing with what has been sent us from the Parisian observatory, it appears to have been at eight hours eight minutes apparent time at London. And the sun being then in $9\frac{1}{2}°$ of Aries, the right ascension of the mid-heaven was $130° 45'$, by which the position of the sphere of fixed stars is given. Hence the lucida pleiadum will be found at that time to have been $25\frac{1}{4}°$ high, in an azimuth $6°$ to the northward of the west; and consequently the arch the meteor moved in, was inclined to the horizon with an angle of about $27°$, having its node or intersection with it, nearly south-south-west, as will be more evident by what follows.

At Oxford, five minutes earlier, Mr. John Whiteside, R. S. Soc. Keeper of the Ashmolean Museum, and very skilful in both mathematical and physical matters, immediately after the extinction of the meteor, made haste out to see what it might be; and well considering the situation of the track it had left in the sky, found it to have passed about $1\frac{1}{2}°$ above the preceding shoulder of Orion, and about $3\frac{1}{2}°$ above the middle of his Belt, where there appeared a luminous nubecula of a reddish light, being a dilation of the track, seeming to have been occasioned by some explosion there; and by what he could learn from those that saw it, it was thereabout that it broke out, and first began to efface the stars. Hence it proceeded

as to sense, in an arch of a great circle; and passing in the middle between the tail of Lepus, Bayer's θ and β in the fore-foot of Canis Major, it terminated about ξ in the breast of the same, nearly in 95° of right ascension, with 23° south declination; and at the place of its extinction there remained a large whitish nebula, much broader, and of a stronger light, than the rest of the track, which he took for a certain indication of a very great explosion made there. By computation, it will be found that the angle this track made with the horizon of Oxford was nearly 40°, and its intersection due S. S. W.; and that the place of its extinction was about 9° above the horizon in the azimuth of 32° to the west.

At Worcester, Mr. Nicholas Fatio, a person greatly skilled in astronomical affairs, saw this meteor descend obliquely towards the south, making an angle with the horizon of about 65°, and intersecting it about S. S. W. ½ S. The track left all Orion and Canis Major to the westward, and divided the distance between Sirius and Procyon, so as to be almost twice as far from Procyon as Sirius. The time here was one minute before eight, this city being about nine minutes of time to the west of London, and consequently the right ascension of the mid-heaven 128½ degrees.

Now the situation of the three cities, London, Oxford, and Worcester, being nearly on the same W. N. W. point, on which the track of the meteor had its greatest altitude above the horizon, equal to the angle of its visible way; if we suppose it at London to have been 27 degrees high, and at the same time at Worcester to be 65 degrees high, in the plane of the vertical circle passing through London and Worcester; supposing likewise the distance between them to be 90 geographical miles, or one degree and a half of an arch of a great circle of the earth, we shall, by an easy trigonometrical calculus, find the perpendicular height to have been 64 such miles; and the point over which it was then perpendicular to have been 30 such miles W. N. W. from Worcester; and the geographical mile to the English statute mile being nearly as 23 to 20, this height will be no less than 73½ English miles; the place directly under it will be found to be about Presteign, on the confines of Hereford and Radnorshires. The Oxford observation nearly agrees in the same conclusion.

This altitude being added to the semidiameter of the earth as radius, becomes the secant of 11 degrees: so that the meteor might

be seen above the horizon, in all places not more than 220 leagues distant from it. Whence it will not be strange that it should be seen over all parts of the islands of Great Britain and Ireland, over all Holland, and the hither parts of Germany, France, and Spain, at one and the same instant of time.

This suggests a considerable use that might be made of these momentaneous phænomena, for determining the geographical longitudes of places. For if, in any two places, two observers, by help of pendulum clocks duly corrected by celestial observation, exactly note at what hour, minute, and second, such a meteor as this explodes and is extinguished, the difference of those times will be the difference of longitude of the two places, as is well known.

Having thus fixed one point in the line of its motion, let us now consider what course the meteor took from thence. And first at the town of Kirby Stephen, on the borders of Yorkshire and Westmorland, in a meridian very little to the westward of Worcester, but about two degrees and a half more to the north, it was observed to break out as from a dusky cloud, directly under the moon, and from thence to descend, nearly in a perpendicular, almost to the horizon. Now the moon, being at that time in the third degree of Leo, was about half an hour past the meridian, and consequently much about a point to the west, or S. by W.: and the situation of Presteign from Kirby-Steven being sufficiently near on the same point, it follows that the direction of the track of the meteor was according to the great circle passing over those two places.

And this is further confirmed by the observation of Sam. Cruwys, Esq. Reg. S. S., who, at Tiverton, about twelve geographical miles nearly due north from Exeter, observed the first explosion of this meteor exactly in his zenith, as he was assured by applying his eye to the side of his door, which he took to be perpendicular, and looking upwards: and from thence he saw it descend to the southward, directly in the same azimuth, without declining either to the right or left. Hence it is plain, that the track likewise passed over this place, which by our best maps is found to lie in a line with Presteign and Kirby-Steven; so that we shall take it for granted that this was the very course it held.

On this supposition, that the first explosion, attended with the reddish nubecula, was directly over Tiverton, we have the Oxford

observation to compare with it, in order to determine more nicely the perpendicular altitude there. At Oxford this nubecula was found to be $3\frac{1}{2}°$ above the middle star of Orion's girdle, at 8h. 3 m. and was therefore $26\frac{1}{2}°$ above the horizon; and the distance between Oxford and Tiverton being 1° 55′, or 115 geographical miles, it will be as the sine of 61° 35′ is to the sine of 63° 30′, so is the semi-diameter of the earth, or $3437\frac{3}{4}$ such miles, to 3498 miles, the distance of the meteor from the centre of the earth; from which deducting the semi-diameter, there remains $60\frac{1}{4}$ geographical miles, for the height of the meteor above Tiverton. And this is confirmed by the observation of the Rev. Mr. William Derham, who at Windsor saw the aforesaid nubecula about two degrees above the most southern of the seven stars in the shield of Orion; that is (the time being 8 h. 6 m.) in the altitude of $23\frac{1}{2}°$: whence the distance between Tiverton and Windsor being 150 measured miles, or 130 geographical, by a like proportion we shall find the same height of the meteor 60 such miles, wanting only one quarter. So that in a round number, we may conclude it to have been just 60 geographic, or 69 statute miles, above the earth's surface. It is impossible to come at a precise determination of this matter; by reason of the coarseness and inaccuracy of the data, which were only the notes of persons under the surprise of the suddenness of the light, and no ways pretending to exactness: however, such as they are, they abundantly evince the height to have exceeded 60 English miles, though some would have it to be no more than 38 or 40.

I was unwilling to leave off, till I had pitched on some hypothesis that might subject the motion of this meteor to a calcalus; that the curious might be able to compute its visible way, either in respect of the horizon, or among the fixed stars: this I found might be done with tolerable exactness, supposing that it moved in the arch of a circle concentric with the earth, and 60 geographical miles without it; and that the point of the first explosion was over the lat. of 50° 40′, and 3° 40′ to the west of London; and that of the last extinction over lat. 47° 40′, with 4° 50′ west longitude; the time being fixed to eight minutes past eight at London. Hence it will be easy, by a trigonometrical process, to obtain the visible altitude and azimuth of the meteor at either of its explosions, as seen from any place whose longitude and latitude is known; and from the time given, the points in the sphere of stars answering to those azimuths

and altitudes are readily deduced. And let those who contend for a much less height of this meteor, try if they can, on such their supposition, to reconcile the several phænomena with one another, and with the observation of the Rev. Mr. William Ella, rector of Rampton in Nottinghamshire, between Gainsborough and Redford, which for its exactness I must not omit. Here, at 8 h. 5 m. the meteor was seen to pass precisely in the middle between Sirius and the fore foot of Canis Major, moving obliquely to the southward, in a line whose direction seemed to be from the middle between the two shoulders of Orion; the latitude of the place being nearly 53° 20′, and long. west. from London 0° 45′. Let them try how they can account for its being seen five degrees high at Aberdeen in Scotland, and near as much at Peterhead, half a degree more northerly: and then they will be better able to judge whether it did not exceed the reputed limits of our atmosphere. Lastly, if the apparent altitude of the meteor at Paris was not five degrees and a half, but eleven, on the W. by N. point, when it must have been in its greatest lustre, there will be no pretence to bring it lower than I have made it; especially if it be allowed to have followed the track I have assigned it, over Presteign, Cardiff, Minehead, Tiverton, and Brest in Bretany.

Allowing this to have been the path it moved in, it would be easy to assign the real magnitude and velocity of this meteor, if the several accounts of its apparent diameter, and of the time of its passage from one of its explosions to the other, were consistent among themselves. But some of them making its visible appearance nearly equal to the sun's, which in the opinion of many it far exceeded, we may suppose with the least that, at the time when it first broke out over Tiverton, its diameter was half a degree; and its horizontal distance being 150 geographical miles from London, and its altitude 60, the hypothenusal, or real distance from the eye, will be more than 160 such miles; to which radius the subtense of half a degree will be above an English mile and half, being about 2800 yards nearly. After the same manner it is difficult to assign its due velocity, while some make it half, others less than a quarter, of a minute, in passing from its first explosion to its last extinction: but the distance it moved in that time being about three degrees, or 180 geographical miles, we may modestly compute it to have run above 300 such miles in a minute; which is a swiftness wholly incredible;

and such, that if a heavy body were projected horizontally with the same, it would not descend by its gravity to the earth, but would rather fly off, and move round its centre in a perpetual orbit like that of the moon.

Of several accidents that were reported to have attended its passage, some were the effect of pure fancy; such as the hearing it hiss as it went along, as if it had been very near at hand; some imagined they felt the warmth of its beams, and others thought they were scalded by it. But what is certain, and no way to be disputed, is the wonderful noise that followed its explosion. All accounts from Devon and Cornwall, and the neighbouring counties, are unanimous, that there was heard there, as it were, the report of a very great cannon, or rather of a broadside, at some distance, which was soon followed by a rattling noise, as if many small arms had been promiscuously discharged. What was peculiar to this sound was, that it was attended with an uncommon tremor of the air, and every where in those counties, very sensibly shook the glass-windows and doors in the houses, and according to some, even the houses themselves, beyond the usual effect of cannon, though near; and Mr. Cruwys, at Tiverton, on this occasion, lost a looking-glass, which being loose in its frame, fell out on the shock, and was broken. We do not know the extent of this prodigious sound, which was heard, against the then easterly wind, in the neighbourhood of London; and by the learned Dr. Tabor, who distinctly heard it beyond Lewes, in Sussex: so that I cannot help thinking, that such a meteor as this might have occasioned that famous ode of Horace: Parcus deorum cultor, &c.

——— Namque Diespiter
Igni corusco nubila dividens,
Plerumque; per purum tonantes
Egit equos volucremque currum,
Quo bruta tellus, &c. Concutitur.———

But whether the report heard near Lewes was of that explosion right over Devonshire, or rather of that latter, and much greater at the extinction over Bretany, I shall not undertake to determine, till we have some further accounts from France, and more satisfactory information to build upon.

It remains to attempt something towards a solution of the un-

common phænomena of this meteor; and by comparing them with things more familiar to us, to shew at least how they might possibly be effected. And first, the unusual and continued heats of the last summer in these parts of the world, may well be supposed to have excited an extraordinary quantity of vapour of all sorts; of which the aqueous, and most others, soon condensed by cold, and wanting a certain degree of specific gravity in the air to buoy them up, ascend but to a small height, and are quickly returned in rain, dews, &c. whereas the inflammable sulphureous vapours, by an innate levity, have a sort of vis centrifuga, and not only have no need of the air to support them, but being agitated by heat, will ascend in vacuo Boileano, and sublime to the top of the receiver, when most other fumes fall instantly down, and lie like water at the bottom. By this we may comprehend how the matter of the meteor might have been raised from a large tract of the earth's surface, and ascend far above the reputed limits of the atmosphere, where, being disengaged from all other particles, by that principle of nature that congregates homogenia, visible in so many instances, its atoms might in length of time coalesce and run together, as we see salts shoot in water, and gradually contracting themselves into a narrower compass, might lie like a train of gunpowder in the ether, till catching fire by some internal ferment, as we find the damps in mines frequently do, the flame would be communicated to its continued parts, and so run on like a train fired.

This may explain how it came to move with so inconceivable a velocity: for, if a continued train of powder were no larger than a barrel, it is not easy to say how very fast the fire would fly along it; much less can we imagine the rapidity of the ascension of these more inflammable vapours, lying in a train of so vast a thickness. If this were the case, as it is highly probable, it was not a globe of fire that ran along, but a successive kindling of new matter: and as some parts of the earth might emit these vapours more copiously than others, this train might, in some parts thereof, be much denser and larger than in others, which might occasion several smaller explosions, as the fire ran along it, besides the great ones, which were like the blowing up of magazines. Thus we may account for the rattling noise like small-arms, heard after the great bounce on the explosion over Tiverton; the continuance of which, for some time, argues that its sound came from distances that increased.

What may be said to the propagation of the sound through a medium, according to the received theory of the air above 300,000 times rarer than what we breathe, and next to a vacuum, I must confess I know not. Hitherto we have concluded the air to be the vehicle of sound; and in our artificial vacuum we find it greatly diminished: but we have this only instance of the effect of an explosion of a mile or two diameter, the immensity of which may perhaps compensate for the extreme tenuity of the medium.

[*Phil. Trans.* 1719.

SECTION IV.

Meteor of a Flaming Sword, seen in Yorkshire, and other neighbouring Counties, May 18, 1710.

By Mr. Ralph Thoresby.

A STRANGE meteor was seen at Leeds, on Holy Thursday, 1710, which the common people call a flaming sword. It was seen in the neighbouring towns, but a great way north, as also above fifty miles south of Leeds. It appeared here at a quarter past ten at night, and took its course from south to north: it was broad at one end, and small at the other; and was by some thought to resemble a trumpet, and moved with the broad end foremost. The light was so sudden and bright, that people were startled to see their own shadows, when neither sun nor moon shone upon them. This is remarkable, that all persons, though at many miles distance from each other, when they saw it, thought it fell within three or four furlongs of them, and that it went out with bright sparklings at the small end. An ingenious clergyman told me, that it was the strangest *deceptio visus* he was ever sensible of, if it was not absolutely extinguished within a few paces of him; and yet others saw it many miles off, further north, in a few moments. It was likewise seen in the counties of Nottingham and Derby, as well as those of York and Lancaster.

[*Ibid.* 1711.

SECTION V.

Luminous Meteor, seen at Peckham, Dec. 11, 1741.

By Thomas Milner, M. D.

Dec. 11, 1741, at seven minutes past one in the afternoon, a globe of light, somewhat larger than the horizontal full moon, and as bright as the moon appears at any time while the sun is above the horizon, instantaneously appeared, in a clear blue sky, about the S. S. E. moving towards the east with a continual equable motion, and leaving behind it a narrow streak of light, whiter than the globe itself, throughout its whole course. Towards the end it appeared less than at the beginning of its motion; and within three, or at most four, seconds, it suddenly vanished. Its apparent velocity was nearly equal to half the medium velocity of those usual meteors commonly called falling or shooting stars.

The narrow luminous streak remained very distinct after the globe was gone; and gave a fair opportunity for taking the elevation of this phenomenon above the horizon, at the beginning and end of its motion, &c. which was found to be twenty degrees. This luminous track, or path, seemed a right line, not quite parallel, but a little inclined to the plane of the horizon, viz. highest towards the east. It was at first very narrow, and pointed at each extremity; but soon grew broader, and within twenty minutes after the appearance, it was exactly like a long bright rare cloud, discontinued in two places, above three times its first breadth, and a little more inclined to, and elevated above, the horizon, than it was immediately after the motion of the globe.

[*Phil. Trans.* 1742.

SECTION VI.

Account of some late Fiery Meteors, with Observations.

By Charles Blagden, M. D. Sec. R. S.

This account respects chiefly the two most remarkable of the meteors that had lately appeared, and is founded partly on private communications, and partly on such accounts as were published in

the newspapers. These meteors were of the kind known to the ancients by the names of Λαμπαδες Πιθοι, Bolides, Faces, Globi, &c. from particular differences in their shape and appearance, and sometimes, it seems, under the general term of comets: in the Philosophical Transactions they are called indiscriminately fire-balls, or fiery meteors; and names of a similar import have been applied to them in the different languages of Europe. The most material circumstances observed of such meteors may be brought under the following heads. 1. Their general appearance. 2. Their path. 3. Their shape or figure. 4. Their light and colours. 5. Their height. 6. Their noise. 7. Their size. 8. Their duration. 9. Their velocity.

Dr. B. begins with the first of these meteors, which was seen August 18, 1783.

§ 1. Its general appearance in these parts of Great Britain was that of a luminous ball, which rose in the N. N. W. nearly round, became elliptical, and gradually assumed a tail as it ascended, and in a certain part of its course seemed to undergo a remarkable change, compared to bursting: after which it proceeded no longer as an entire mass, but was apparently divided into a great number, or a cluster of balls, some larger than the others, and all carrying a tail or leaving a train behind: under this form it continued its course with a nearly equable motion, dropping or casting off sparks, and yielding a prodigious light, which illuminated all objects to a surprising degree; till having passed the east, and verging considerably to the southward, it gradually distended, and at length was lost out of sight. The time of its appearance was 9 h. 16 min. P. M. mean time of the meridian of London, and it continued visible about half a minute.

§ 2. How far north the meteor may have begun there are no materials to determine with precision; but, as it was seen in Shetland, and at sea between the Lewes and Fort William, and appeared to persons at Aberdeen and Blair, in Athol, ascending from the northward; and to an observer in Edinburgh as rising like the planet Mars; there can be little doubt but its course commenced beyond the farthest extremity of this island, somewhere over the northern ocean. General Murray, F.R.S. being then at Athol House, saw it pass over his head as nearly vertical as he could judge, tracing it from about 45 degrees of elevation north-north-westward to 30 or

20 degrees south-south-eastward, where a range of buildings intercepted it from his view. From near the zenith of Athol House, it passed on a little westward of Perth, and probably a little eastward of Edinburgh; and continuing its progress over the south of Scotland, and the western parts of Northumberland, and the bishopric of Durham, proceeded almost through the middle of Yorkshire, leaving the capital of that county somewhat to the eastward. Hitherto its path was as nearly S. S. E. as can be ascertained; but somewhere near the borders of Yorkshire, or in Lincolnshire, it appears to have gradually deviated to the eastward; and in the course of that deviation to have suffered a very remarkable change in the nature of its appearance, and to have separated into two parts. After this division the compact cluster of smaller meteors seems to have moved for some time almost S. E. thus traversing Cambridgeshire, and perhaps the western confines of Suffolk; but gradually recovering its original direction, it proceeded over Essex and the Straits of Dover, entering the continent probably not far from Dunkirk, where, as well as at Calais and Ostend, it was thought to be vertical. Afterwards it was seen at Brussels, Paris, and Nuits in Burgundy, still holding on its course to the southward; nay, there is an intimation, though of doubtful authority, that it was perceived at Rome. Our information of its progress over the continent is indeed very defective and obscure; yet we have sufficient proof that it traversed in all thirteen or fourteen degrees of latitude, describing a track of 1000 miles at least over the surface of the earth; a length of course far exceeding the utmost that has been hitherto ascertained of any similar phenomenon.

§ 3. This meteor was described by most spectators under three different forms, and is so represented by Mr. Sandby in his beautiful drawing; but the first two of those do not imply any real variation in its shape, depending only on a difference in the point of view. Accordingly, in the first part of its course over Scotland, it was seen to have a tail, and is thus described by General Murray when it passed Athol House. Two causes concur in this deception; first the fore-shortening, and even occultation, of the tail, when the object is seen nearly in front; and, 2dly, that the light of most part of the tail is of so inferior a kind, as to be difficultly perceived at a great distance, especially when the eye is dazzled by the overpowering brilliancy of the body. The length and shape of the tail, however,

were perpetually varying; nor did the body continue always of the same magnitude and figure; but was sometimes round, at other times elliptical, with a blunt or a pointed protuberance behind. From such changes of figure in this and other meteors it is, that they have been compared to columns or pyramids of fire, comets, barrels, bottles, flasks, paper-kites, trumpets, tad-poles, glass drops, quoits, torches, javelins, goats, and many other objects; whence the multifarious appellations given to them by the ancients were borrowed.

Respecting the tails of meteors, it is here necessary to distinguish between two different parts of which they consist. The brightest portion seems to be of the same nature as the body, and indeed an elongation of the matter composing it; but the other, and that commonly the largest portion, might more properly be called the train, appearing to be a matter left behind after the meteor has passed; it is far less luminous than the former part, and often only of a dull or dusky red colour. A similar train or streak is not unfrequently left by one of the common falling stars, especially of the brighter sort; and vestiges of it sometimes remain for several minutes. It often happens, that even the large fire-balls have no other tail but this train, and this of the 18th of August appeared at times to be in that state; its tail was thought by some spectators to be spiral.

Under this changeable form, but still as a single body, it proceeded regularly till a certain period; when expanding with a great increase of light, it separated into a cluster of smaller bodies or ovals, each extended into a tail, and producing a train. At the same time a great number of sparks appeared to issue from it in various directions, but mostly downward, some of which were so bright as also to leave a small train. Most fire-balls have suffered a bursting or explosion of this kind; but, in general, they have been thought to disappear immediately afterwards. This, however, continued its course, becoming more compact, or perhaps re-uniting, and seems to have undergone other similar explosions before it left our island, and again on the continent. The different accounts tend to shew, that its first separation or bursting happened somewhere over Lincolnshire, perhaps near the commencement of the fens. It is observable, that the great change in this meteor corresponds with the period in which it suffered a deviation from its

course, as if there were some connexion between those two circumstances; and there are traces of something of the same kind having happened to other meteors. If the explosion be any sort of effort, we cannot wonder that the body should be moved by it from a straight line; but, on the other hand, it seems equally probable, that if the meteor be forced, by any cause, to change its direction, the consequence should be a division or separation of its parts.

§ 4. Nothing relative to these meteors strikes the beholders with so much astonishment as the excessive light they afford, sufficient to render very minute objects visible on the ground in the darkest night, and larger ones to the distance of many miles from the eye. The illumination is often so great as totally to obliterate the stars, to make the moon look dull, and even to affect the spectators like the sun itself; nay, there are many instances in which such meteors have made a splendid appearance in full sun-shine. The colour of their light is various and changeable, but generally of a bluish cast, which makes it appear remarkably white. A curious effect of this was observed at Brussels, the 18th of August, that while the meteor was passing, "the moon appeared quite red, but soon recovered its natural light." The brightness alone of the meteor, is not sufficient to explain this, for the moon does not appear red when seen by day; but it must have depended on the contrast of colour, and shows how large a proportion of blue rays enters into the composition of that light, which could make even the silver moon appear to have excess of red. Prismatic colours were also observed in the body, tail, and sparks of this meteor, variously by different persons; some compared them to the hues of gems. The moment of its greatest brightness seems to have been when it burst the first time; but it continued long to be more luminous after that period than it was before.

The body of the fire-ball, even before it burst, did not appear of an uniform substance or brightness, but consisted of lucid and dull parts, which were perpetually changing their respective positions; so that the whole effect was to some eyes like an internal agitation or boiling of the matter, and to others like moving chasms or apertures. Similar expressions have been used in the description of former meteors. The luminous substance was compared to burning brimstone or spirits, Chinese fire, the stars of a rocket, a pellucid ball or bubble of fire, liquid pearl, lightning, and electrical fire;

few persons fancied it to be solid, especially when it came near the zenith. Different spectators observed the light of the meteor to suffer at times a sudden diminution and revival, which produced an appearance as of successive inflammation ; but might in some cases, at least, be owing to the interposition of small clouds in its path.

§ 5. When, in consequence of a more accurate attention to natural philosophy, such observations were first made on fire-balls as determined their height, the computers were with reason surprized to find them moving in a region so far above that of the clouds and other familiar meteors of our atmosphere ; especially as to every uninformed spectator they appear extremely near, or as if bursting over his head, a natural effect of their great light when seen without intervening objects. Their real height is to be collected from observations made at distant stations ; which, for the greatest accuracy, ought to be so situated, that the line joining them may cut the path of the meteor at right angles ; and that, at its greatest elevation, it may appear from both of them about 45 degrees above the horizon, on opposite sides of the zenith. Dr. B. laments that most of the observations in his possession of the meteor of August 18, give its altitude by estimation only ; yet their correspondence with each other may gain them a degree of credit, to which, if single, they would not be entitled. Dr. B. here relates eight or nine accounts of the height and motion of this meteor, from which he calculates its perpendicular height above the earth's surface in most of these instances, and finds they run from 57 to 60 miles in height. And further observes, this agreement of the different altitudes is nearer than could be expected; and therefore we may safely conclude, that it must have been more than 50 miles above the surface of the earth, in a region where the air is at least 30,000 times rarer than here below.

§ 6. That a report was heard some time after the meteor of the 18th of August had disappeared, is a fact which rests on the testimony of too many witnesses to be controverted, and is conformable to what has been observed in most other instances. In general it was compared to the falling of some heavy body in a room above stairs, or to the discharge of one or more large cannon at a distance. That rattling noise, like a volley of small arms, which has been remarked after other meteors, does not seem to have been heard on this occasion. From a comparison of the different accounts, it

appears as if the report was loudest in Lincolnshire and the adjacent countries, and again in the eastern parts of Kent; in the intermediate places it was so indistinct as generally not to have been noticed, and all observers of credit in Scotland deny that they heard any thing of the sort. If this report then be connected with the bursting of the meteor, it would seem as if that sound was produced two separate times, namely, at the first explosion over Lincolnshire, and again when it seemed to burst soon after entering the continent. Ingenious men have availed themselves of this sound, to calculate the distance and height of meteors; and the exactness attained by this method, in the computation of the late fire-ball, from the report heard at Windsor, is very remarkable; but, in general, the accounts disagreed so much, that it would have been impossible to conclude any thing from them. Besides the report, as of explosions, which was heard after the meteor, another sort of sound was said to attend it, more doubtful in its nature, and less established by evidence; viz. a kind of hissing, whizzing, or crackling, as it passed along. That sound should be conveyed to us in an instant from a body above 50 miles distant, appears so irreconcileable to all we know of philosophy, that perhaps we should be justified in imputing the whole to an affrighted imagination, or an illusion produced by the fancied analogy of fire-works. The testimony in support of it is, however, so considerable, on the occasion of this as well as former meteors, that Dr. B. cannot venture to reject it, however improbable it may be thought, but leaves it as a point to be cleared up by future observers.

§ 7. To determine the bulk of the fire-ball, we must not only have calculated its distance, but also know the angle under which it appeared. For this purpose the moon is the usual term of comparison; but as it was thought, at very different distances, to present a disc equal to that luminary's, and the same expressions have been applied to most preceding fire-balls, Dr. B. conceives this estimation rather to be a general effect of the strong impression produced by such splendid objects on the mind, than to convey any determinate idea of their size. However, if we suppose its transverse diameter to have subtended an angle of 30 minutes when it passed over the zenith, which probably is not very wide of the truth, and that it was 50 miles high, it must have been almost half a mile across. The tail sometimes appeared ten or twelve times

longer than the body: but most of this was train, and the real elongation behind seems seldom to have exceeded twice or thrice its transverse diameter; consequently, was between one and two miles long. Now if the cubical contents be considered, for it appeared equally round and full in all directions, such an enormous mass, moving with extreme velocity, affords just matter of astonishment.

§ 8. The duration of the meteor is very differently stated; partly because some observers had it in view a much longer time than others; and partly because they formed different judgments of the time. Those who saw least of it seem to have perceived its illumination about ten seconds, and those who saw most of it, about a minute: hence the various accounts may in some measure be reconciled. Mr. Herschel, F.R.S. at Windsor, must have kept it in sight long after other observers had thought it extinct: for though probably he did not see the beginning, as it never appeared to him like a single ball, he watched it as much as "40 or 45 seconds, the last 20 or 25 of which it remained almost in one situation, within a few degrees of the horizon." This confirms the foreign accounts of its long progress to the southward.

§ 9. From the apparent motion of the meteor, compared with its height, some computation may be formed of its astonishing velocity. As at the height of 50 miles above the surface of the earth, it might be visible from the same station for a tract of more than 1200 miles, and the longest continuance of its illumination scarcely exceeded a minute, we have hence some presumption that it moved not less than 20 miles in a second. The Rev. Mr. Watson, in his letter to Lord Mulgrave, says, that the arc described by it, while in his view, could not be less than 70 or 80 degrees, and yet the time could not exceed four seconds, or five at most: this, with an altitude of 60 degrees and height of 50 miles, gives for its velocity about 21 miles in a second. The observer at Newton Ardes estimated its motion to be 30 miles in a second. Mr. Herschel found it describe an arc of 167 degrees during the 40 or 45 seconds he observed it, which gives a velocity of more than 20 miles in a second. Finally, Mr. Aubert, F.R.S. thought it described an arc of 136 degrees of azimuth in ten or twelve seconds, which would make its velocity above 40 miles in a second. Dr. B. is sensible of the objections that may be made to all these computations; undoubtedly they are too vague; and yet, all taken together, perhaps they may have

some weight; especially as they correspond so well with the different phænomena of the meteor's duration, and other fire-balls have been computed to move as fast. Stating the velocity at the lowest computation of 20 miles a second, it exceeds that of sound above 90 times, and begins to approach toward that of the earth in her annual orbit. At such a rate, it must have passed over the whole island of Great Britain in less than half a minute, and might have reached Rome within a minute afterwards, or in seven minutes have traversed the whole diameter of the earth! From this calculation it will be evident, that there is little chance of determining the velocity of meteors from the times of their passing the zenith of different places; and that, therefore, we must principally depend on observing carefully, with a watch that shews seconds, their apparent velocity through the heavens.

The fire-ball which appeared October 4th, at 43 minutes past six in the evening, was much smaller than that already described, and of much shorter duration. It was first perceived to the northward as a stream of fire, like the common shooting stars, but large; and having proceeded some way under this form, it suddenly burst out into that intensely bright bluish light which is peculiar to such meteors. At this period Dr. B. saw it, and could compare the colour to nothing so well as to the blue lights of India, and some of the largest electrical sparks. The illumination was very great; and on that part of its course where it had been so bright, a dusky red streak or train was left, which remained visible perhaps a minute, even with a candle in the room, and was thought by some gradually to change its form. Except this train, he thought the meteor had no tail, but was nearly of a round body, or perhaps a little elliptical. After moving not less than ten degrees in this bright state, it became suddenly extinct, without any appearance of bursting or explosion.

This meteor was seen for so short a way, that it was scarcely possible to determine the direction of its course with accuracy; but as in proceeding to the eastward it very perceptibly inclined towards the horizon, it certainly moved somewhere from the north-westward to the south-eastward. Its duration was so short, that many persons thought it passed in an opposite direction; for his own part he found himself absolutely unable to determine whether the motion was from or toward the south-east. Some spectators were of opinion, that it changed its course the moment it became bright, proceeding

no longer in the same straight line; but his information was not sufficient to determine this question. From his own, and another observation, Dr. B. calculates that the height of the meteor above the surface of the earth, after all proper allowances are made, must have been between 40 and 50 miles.

As there was no appearance of bursting at the extinction of this fire-ball, so no report was heard after it; nor did any sound attend it. Some observers thought this meteor also near as large as the moon; but to Dr. B. it did not appear above one quarter of her diameter, which would make its breadth somewhat above a furlong. If the whole of the meteor's track be included, it seems to have lasted as much as three seconds, but in the bright state its duration was less than two; he thinks not much above one. Supposing it described an arc of 14 degrees in a second and a half, or, according to Mr. Aubert's observation, of 25 degrees in three seconds, its real velocity was about twelve miles a second.

Such meteors as these, which pass like a flash of lightning, and describe so short a course, are very unfavourable for calculating the velocity; but afford great advantages for determining the height, as they must be seen nearly at the same moment and in the same place by the different observers. Other instances are found of fire-balls beginning with a dull red light, like a falling star, particularly the great one of March 19, 1719, treated of so fully by Dr. Halley and Mr. Whiston *. It is remarkable, that a similar meteor had appeared the same day, that is, Saturday the 4th of October, about three in the morning, though, on account of the early hour, it was seen by fewer spectators. They represent it as rising from the northward to a small altitude, and then becoming stationary with a vibratory motion, and an illumination like day-light, it vanished in a few moments, leaving a train behind. This sort of tremulous appearance has been noticed in other meteors, as well as their continuing stationary for some time, either before they began to shoot forward, or after their course was ended.

I find it impossible to quit this subject, says Dr. B. without some reflections about the cause, that can be capable of producing such appearances at an elevation above the earth; where, if the atmosphere cannot absolutely be said to have ceased, it is certainly to be

* Account of a surprising meteor seen March 19, 1719.—Orig.

considered as next to nothing. The first idea which suggested itself, that they were burning bodies projected with such a velocity, was quickly abandoned, from the want of any known power to raise them up to that great height; or, if there, to give them the required impetus; and the ingenuity of Dr. Halley soon furnished him with another hypothesis, in which he thought both these difficulties obviated. He supposes there is no projection of a single body in the case; but that a train of combustible vapours, accumulated in those lofty regions, is suddenly set on fire, whence all the phænomena are produced by the successive inflammation. But Dr. Halley gives no just explanation of the nature of these vapours; nor of the manner in which they can be raised up through air so extremely rare; nor, supposing them so raised, does he account for their regular arrangement in a straight and equable line of such prodigious extent, or for their continuing to burn in such highly-rarefied air. Indeed, it is very difficult to conceive how vapours could be prevented, in those regions where there is, in a manner, no pressure, from spreading out on all sides in consequence of their natural elasticity, and instantly losing that degree of density which seems necessary for inflammation. Besides, it is to be expected, that such trains would sometimes take fire in the middle, and so present the phenomenon of two meteors at the same time, receding from each other in a direct line.

These difficulties have induced other philosophers to relinquish Dr. Halley's hypothesis; and propose, instead of it, one of a very opposite nature; that meteors are permanent solid bodies, not raised up from the earth, but revolving round it in very eccentric orbits; or, in other words, that they are terrestrial comets. The objections to this opinion, however, seem equally great. Most observers describe the meteors, not as looking like solid bodies, but rather like a fine luminous matter, perpetually changing its shape and appearance. Of this, many defenders of the opinion are so sensible, that they suppose the revolving body gets a coat or atmosphere of electricity, by means of which it becomes luminous; but whoever carefully peruses the various accounts of fire-balls, and especially ours of the 18th of August when it divided, will perceive that their phænomena do not correspond with the idea of a solid nucleus enveloped in a subtile fluid; any more than with the conjecture of another learned gentleman, that they become luminous by means of a contained

fluid, which occasionally explodes through the thick solid outer shell.

A strong objection to this hypothesis of permanent revolving bodies, is derived from the great number of them there must be to answer all the appearances. Such a regular gradation is observed from those large meteors which strike all beholders with astonishment, and occur but rarely; down to the minute fires called shooting stars, which are seen without being regarded in great numbers every clear night; that it seems impossible to draw any line of distinction between them, or deny that they are all of the same nature. But such a crowd of revolving bodies could scarcely fail to announce their existence by some other means than merely a luminous train in the night; as, for instance, by meeting or justling sometimes near the earth, or by falling to the earth in consequence of various accidents; at least we might expect they would be seen in the day-time, either with the naked eye, or by telescopes, by some of the numerous observers who are constantly examining the heavens.

Another argument of great weight, against the hypothesis that fire-balls are terrestrial comets, is taken from their great velocity. A body falling from infinite space toward the earth, would have acquired a velocity of no more than seven miles a second, when it came within 50 miles of the earth's surface; whereas these meteors seem to move at least three times faster. And this objection, if there be no mistake in regard to the velocity of the meteor, as I think there is not, absolutely oversets the whole hypothesis.

What then can these meteors be? The only agent in nature with which we are acquainted, that seems capable of producing such phænomena, is electricity *. I do not mean that by what is already

* Since the above was written, other ways of accounting for these meteors have been discovered, and such indeed as, agreeing very well with all the phænomena, seem to be probable, or at least possible, solutions; which is far more than can be said of the notion from electricity; a notion that hardly agrees with any one of the numerous extraordinary circumstances attending these meteors; which have been observed in many instances to be the same as the stony masses that have often fallen through the atmosphere on various parts of the earth. For a particular account of such phænomena, see *Meteoric Stones*, section viii. of the present chapter. It is remarkable of the present large meteor, that its calculated velocity is nearly equal to that of the earth in its annual motion in the opposite direction.

known of that fluid, all the difficulties relative to meteors can be solved; as the laws, by which its motions on a large scale are regulated in those regions so nearly empty of air, can scarcely, I imagine, be investigated in our small experiments with exhausted vessels; but only that several of the facts point out a near connexion and analogy with electricity, and that none of them are irreconcileable to the discovered laws of that fluid.

1. Electricity moves with such a prodigious velocity, as to elude all the attempts hitherto made by philosophers to detect it; but the swiftness of meteors, stating it at twenty miles a second, is such as no experiments yet contrived could have discovered, and which seems to belong to electricity alone. This is, perhaps, the only case in which the course or direction of that fluid is rendered perceptible to our senses, in consequence of the large scale on which these fire-balls move.

2. Various electrical phænomena have been seen attending meteors. Lambent flames are described as settling on men, horses, and other objects; and sparks coming from them, or the whole meteor itself, it is said, have damaged ships, houses, &c. in the manner of lightning. These facts, I must own, are but obscurely related, yet still they do not seem to be destitute of foundation. If there be really any hissing noise heard while meteors are passing, it seems explicable on no other supposition than that of streams of electric matter issuing from them, and reaching the earth with a velocity equal to that of the meteor, namely, in two or three seconds. Accordingly, in one of our late meteors, the hissing was compared to that of electricity issuing from a conductor. The spark flying off so perpetually from the body of fire balls, may possibly have some connexion with these streams. In the same manner the sound of explosion may be brought to us quicker, than if it were propagated through the whole distance by air alone. Should these ideas be well founded, the change of direction which meteors seem at times to undergo, may possibly be influenced by the state of the surface of the earth over which they are passing, and to which the streams are supposed to reach. A similar cause may occasion the apparent explosion, the opening of more channels giving new vent and motion to the electric fluid. May not the deviation and explosion which appear to have taken place in the fire-ball of the 18th

of August over Lincolnshire, have been determined by its approach towards the fens, and an attraction produced by that large body of moisture?

3. A further argument for the electric origin of meteors is deducd from their connexion with the northern lights, and the resemblance they bear to these electrical phænomena, as they are now almost universally allowed to be, in several particulars. Instances are recorded, where northern lights have been seen to join and form luminous balls, darting about with great velocity, and even leaving a train behind like the common fire-balls. This train I take to be nothing but the rare air left in such a highly-electrified state as to be luminous; and some streams of the northern lights are very much like it. The aurora borealis appears to occupy as high, if not a higher, region above the surface of the earth; as may be judged from the very distant countries to which it has been visible at the same time; indeed, the great accumulation of electric matter seems to lie beyond the verge of our atmosphere, as estimated by the cessation of twilight. Also with the northern lights a hissing noise is said to be heard in some very cold climates; Gmelin speaks of it in the most pointed terms, as frequent and very loud in the north-eastern parts of Siberia; and other travellers have related similar facts.

But, in my opinion, the most remarkable analogy of all, and that which tends most to elucidate the origin of these meteors, is the direction of their course; which seems, in the very large ones at least, to be constantly from or toward the north or north-west quarter of the heavens, and indeed to approach very nearly to the present magnetical meridian. This is particularly observable in those meteors of late years whose tracks have been ascertained with most exactness; as that of November 26, 1758, described by Sir John Pringle; that of July 17, 1771, treated of by M. Le Roy; and this of the 18th of last August. The largest proportion of the other accounts of meteors confirm the same observation, even those of a more early period; nay, I think some traces of it are perceivable in the writings of the ancients. Whether their motion shall be from the northern quarter of the heavens or towards it, seems nearly indifferent, as the numbers of those going each way are not very unequal; I consider them in the former case as masses of the electric fluid repelled or bursting from the great collected body of it in the

north; and in the latter case, as masses attracted to that accumulation; a distinction probably much the same in effect, as that of positive and negative electricity near the surface of the earth.

This tendency toward the magnetic meridian, however, seems to hold good only with regard to the largest sort of fire-balls; the smaller ones move more irregularly; perhaps because they become farther within the verge of our atmosphere, and are thus more exposed to the action of extraneous causes. That the smaller sort of meteors, such as shooting stars, are really lower down in the atmosphere, is rendered very probable by their swifter apparent motion; perhaps it is this very circumstance which occasions them to be smaller, the electric fluid being more divided in more resisting air. But as those masses of electricity, which move where there is scarcely any resistance, so generally affect the direction of the magnetic meridian, the ideas which have been entertained of some analogy between these obscure powers of nature, seem not altogether without foundation.

If the foregoing conjectures be just, distinct regions are allotted to the electrical phænomena of our atmosphere. Here below, we have thunder and lightning, from the unequal distribution of the electric fluid among the clouds; in the loftier regions whither the clouds never reach, we have the various gradations of falling stars; till, beyond the limits of our crepuscular atmosphere, the fluid is put into motion in sufficient masses to hold a determined course, and exhibit the different appearances of what we call fire-balls; and probably at a still greater elevation above the earth, the electricity accumulates in a lighter less condensed form, to produce the wonderfully diversified streams and corruscations of the aurora borealis.

[*Phil. Trans. Abr. vol.* xv. *year* 1784.

SECTION VII.

Fiery Meteors, with Balls that have descended to the Earth.*

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1. *Account of a fiery Meteor seen at Jamaica, to strike into the Earth.*

By Mr. Henry Barham, F.R.S.

About the year 1700, as I was riding one morning about three miles north-west from St. Jago de la Vega, I saw a ball of fire, appearing to me of the size of a bomb-shell, swiftly falling down with a great blaze. When I arrived where it fell, I found the people wondering at the ground being broken in by a ball of fire, which they said fell down there. I observed there were many holes in the ground; one in the middle, of the size of a man's head, and five or six smaller holes round about it, of the size of a man's fist; and so deep, especially the largest, as not to be fathomed by what long sticks they had at hand. It was observed, that the green grass was perfectly burnt near the holes, and a strong smell of sulphur remained thereabouts for a good while after.

We had a very rainy night before, with much lightning and thunder, which is frequent in Jamaica, often killing cattle in the fields. These claps are much louder and stronger than any in Europe, and our showers of rain are also more violent. We have lightning all the year round; but our great rains are in the months of May, August, and October.

Our island is full of mines, and, I question not, very rich. It is very subject to earthquakes; several happening every year, especially after great rains, which fill up all the great cracks in the surface of the earth: for in a very dry time, they are so very large, deep, and gaping so open and wide, that it is dangerous to ride over some parts of the savannas, for fear a horse should get his legs into them. Our earthquakes make a noise or rumbling in the earth, before we feel the shake; and seem to run swiftly to the westward.

[*Phil. Trans.* 1718.

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* See for other instances, chap. xliii. sect. iv.

2. *Ball of Sulphur supposed to be generated in the Air.*

By Mr. Benjamin Cooke, F.R.S.

The great heats we have lately suffered were ushered in by a very gloomy night, of almost continual lightning, accompanied with very loud claps of thunder; which, as usual, were towards the morning followed by very heavy showers of rain. Early next day, in a meadow near the sea-shore, far from any house, and where it has not been known that any improvement has been carried on, a husbandman found a beautiful yellow ball lying on the turf. It proved to be of sulphur, of which it smelt uncommonly strong. It was frosted, as it were, all over with an efflorescence of fine, shining, yellowish crystals, which soon fell off with the lightest touch.

It has on one side a deep hole, admitting the end of a middle-sized knitting needle; and on the opposite side a deep depression, which would induce one almost to think its form had been at first nearly spheroidal, formed by a revolution round a supposed axis connecting those two parts. It has several other holes scattered irregularly up and down its whole surface, some fit to admit a hog's bristle, others a hair; as if it had been made of a fine powder, and some liquid, and after mixing had suffered some fermentation; but those parts of it which are solid, seem more compact than those of the common roll brimstone of the shops, and the powder of it burns with a whiter flame, and less acid fumes. Its longest diameter is between eight or nine, and its shortest betwixt six and seven-tenths of an inch; its weight is 108 grains.

We find frequent mention, in the description of thunder-storms in hot climates, that there falls often a flaming bituminous matter to the ground, which sometimes burns not to be soon extinguished; but more frequently spatters into an infinite number of fiery sparks, doing great damage where they strike, always attended with a sulphureous suffocating smell, commonly compared to that of gunpowder.

Whether this sulphureous ball was intended for one of these, but by some accident missed firing, it is now time to consider. Had it been formed in the earth, how should it get to the surface, without losing that most elegant frosty covering of fine shining crystals, and

appear not in the least sullied, or its pores filled with earth, or other terrestrial matter? on the contrary, not the least adhesion of any thing of that kind can be observed: besides, brimstone made the ordinary way seems to have a different texture of its internal parts from this ball. From these observations Mr. Cooke concludes it not formed in the earth.

[*Id.* 1738.

3. Fire-ball accompanied with a shower of Stones from the Atmosphere.

C. Biot, member of the National Institute, in a letter to the French Minister of the Interior, dated July 20, 1813, gives a detailed account of his inquiries, &c. respecting a fire-ball which exploded in the neighbourhood of Laigle.

On Tuesday, April 26, 1812, about one in the afternoon, the weather being serene, there was observed from Caen, Pont Audemer, and the environs of Alençon, Falaise, and Verneuil, a fiery globe of a very brilliant splendour, which moved in the atmosphere with great rapidity.

Some moments after there was heard at Laigle, and in the environs of that city, in the extent of more than thirty leagues in every direction, a violent explosion, which lasted five or six minutes.

At first there were three or four reports like those of a cannon, followed by a kind of discharge which resembled a firing of musketry; after which there was heard a dreadful rumbling, like the beating of a drum. The air was calm and the sky serene, except a few clouds, such as are frequently observed.

The noise proceeded from a small cloud which had a rectangular form, the largest side being in a direction from east to west. It appeared motionless all the time that the phenomenon lasted. But the vapour of which it was composed was projected momentarily from the different sides by the effect of the successive explosions. This cloud was about half a league to the north-north-east of the town of Laigle; it was at a great elevation in the atmosphere, for the inhabitants of two hamlets, a league distant from each other, saw it at the same time above their heads. In the whole canton over which this cloud hovered, a hissing noise like that of a stone

discharged from a sling was heard; and a multitude of mineral masses, exactly similar to those distinguished by the name of *meteoric stones,* were seen to fall at the same time.

The district, in which the stone fell, forms an elliptical extent of about two leagues and a half in length, and nearly one in breadth; the greatest dimension being in a direction from south-east to north-west, forming a declination of about 22°. This direction which the meteor must have followed is exactly that of the magnetic meridian; which is a remarkable result.

The largest of these stones fell at the south-east extremity of the large axis of the ellipse; the middle-sized ones fell in the centre, and the smallest at the other extremity. It thereby appears that the largest fell first, as might naturally be supposed.

The largest of all those which fell weighs 17½ pounds. The smallest he saw weighed about two gros, which is the thousandth part of the former. The number that fell is certainly *above* two or three thousand. They were friable some days after their fall, and smelled strongly of sulphur. Their present hardness was acquired gradually.

[*Nicholson's Journal.*

SECTION VIII.

Observations on Fire-Balls.

By F. C. Falda.

Notwithstanding the great progress which the sciences have made in the present century; and though our knowledge of the atmosphere has, in particular, been much enlarged; we are still far from being able to explain all its phænomena, especially those of the luminous kind, in a manner sufficiently satisfactory to the cautious and reflecting philosopher. Though many, in consequence of the important discoveries made respecting the electricity of the clouds, imagine that they have found in the electric fluid, so widely diffused, a certain key to all distant phænomena of a similar kind; yet the greater part of them as mere observations, and the explanations given of them as mere hypotheses, must be left to the decision of posterity. It would be useless, and perhaps it is impossible, to mention all these phænomena in any certain order: but the most

singular of them are large fire-balls *(bolides)*, which, on account of their importance in natural philosophy, have in modern times excited universal attention *.

Respecting the origin and nature of these phænomena, which are but seldom seen, and always surprise us as it were accidentally, we can venture conjectures and explanations only when we have compared a series of observations carefully made with the circumstances by which they were attended, and have then deduced from them general conclusions †, which in the hands of the mathematician may conduct with the greatest certainty to a knowledge of their nature, and of the causes by which they are produced. I shall endeavour, therefore, to present the reader with such conclusions drawn from a series of observations made in regard to fire-balls, not with the intention of giving any explanation from them myself, but in compliance with the excellent rule laid down by Le Roy, when he says, speaking of this circumstance: " Let us always collect observations without being too forward to deduce consequences from them, and to explain phænomena respecting which we have at present so little knowledge ‡."

* On the 13th of July, 1797, about 42 minutes after nine in the evening, I had the good fortune, when in company with several of my friends, to see a meteor of this kind. It appeared in the southern part of the horizon, at the height of 8 or 10 degrees; had the form of a perfect globe or sphere well defined at the edges, almost as large as the moon when at full, and proceeded in the space of scarcely a second, while its course was only marked by a fine white streak of light, in an almost perpendicular direction towards our horizon, which was confined by houses, and disappeared behind them. Its colour and splendour near the middle were sometimes of a dazzling white. The heat during the day, and in the evening, was considerable. The thermometer varied from 18 to 20 of Reaumur, and between the hours of four and five in the afternoon there had been a storm in the same quarter of the heavens. At the surface of the earth there was a perfect calm, and in the evening the weather-cocks shewed that a light south-west wind prevailed at some height in the atmosphere. At the time of this phenomenon the earth was overspread by a pale mist, through which no stars could be perceived, and which the following night became a thick fog.

† Il faudroit etudier avec soin les rapports de ces *phénomenes* avec les autres phénomènes atmosphériques; rechercher l'état du ciel avant et aprés leur apparition, déterminer les tems, les circonstances, et lieux, ou ils sont les plus communs, savoir pourquoi ils sont rares, et pourquoi ils arrivent. Que d'observations à faire! Que d'observateurs à occuper!—*Sennebier.*

‡ Memoires de l'Academie des Sciences, 1771.

Some of the observations here given as well as the conclusions drawn from them, have been already employed by Dr. Chladni, in a particular treatise *, to explain the origin of the mass of iron found by Professor Pallas in Siberia †, and other masses of the like kind; as well as stones which, according to accounts worthy of credit, are said to have fallen from the heavens, and therefore more in a geological than a meteorological view. My object is quite different. I propose, notwithstanding the difficulty of determining properly, from the observations made, to what class of luminous appearances such phænomena belong ‡, to collect together those accounts which have been considered, at least with some probability, as alluding to the same kind; and in most cases just as they were given by the observers, without paying attention to any particular mode of explanation, in order to assist those whose attention is occupied with the origin and nature of these bodies; to examine the old and new hypothesis formed respecting them, or to support future ones, if necessary. These meteors appear then—

1. In every climate. Of fifty observations with which I am acquainted, three were made immediately under the equator §; three in a southern ||, and 44 in a northern latitude: and this disproportion

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* Ueber den Ursprung der von Pallas gefundenen und anderer ihr ähnlichen Eisen-Massen, von C. F. F. Chladni. Riga 1794.

† See Philosophical Magazine, Vol. II. p. 1.

‡ Henry Barham, as mentioned in the Philosophical Transactions, vol. xxx. p. 837, saw in Jamaica, in the year 1700, a flaming fire-ball, of the size of a bomb, descend towards the earth; but though the ground was dug up around the place where it seemed to fall, nothing could be perceived except burnt grass and a sulphureous smell. A violent storm, it is said, had taken place a little before, which makes it highly probable that this phenomenon was nothing else than lightning; especially as Reimarus relates, that lightning has been seen to fall upon houses and conductors in a globular form, and that a sulphureous smell has been afterwards perceived; see *Reimarus vom Bliz*, Hamburg 1794, p. 51, 155, 319. An observation of two balls proceeding towards each other before a thunder cloud, made by Hartman, in July 1758, seems to be of the like kind. See *Verwandschaft der Elektrischen Kraft mit den Lufterscheinungen*, Hanover 1759, p. 237; and also a flash of lightning mentioned by Reimarus, p. 12. Other instances of the two phænomena being confounded, are noticed by Dr. Chladni, in his work, p. 2.

§ Ulloa's Voyage to South America. Lond. 1760. Vol. i. p. 354, and vol. ii. p. 226.

|| Journal des Observations Physiques, Mathematiques, et Botaniques, par Louis Feuillé. Paris 1714. Vol. i. p. 116, 119, and vol. iii. p. 92.

arises merely from the greater number of accounts brought to us from the latter, and the greater attention of the observers; for we are assured by Forster, that he saw several fire-balls in the south seas*.

2. At every season of the year. I am acquainted with observations made in every month except September; and of these several were made, but between the 45th and 55th degree of northern latitude, in all the months except April, June, and September. It cannot, therefore, be said that, like storms, they appear more frequently at one time of the year than another.

3. At every period of the day. The hour when these phænomena took place is not indeed given by every observer, but observations have been made both by night and by day. The greater part, however, have been made in the evening; when, being more perceptible to the eye, it was less possible for them to escape notice.

4. They appear, for the most part, when the sky is serene. This remark is expressly made in regard to 26 of the above-mentioned 50; and in regard to the rest, it is to be concluded, from concomitant circumstances, such as their height, &c. The heavens were often covered only with a pale mist †, and some few were seen to proceed from light clouds‡; which gives us reason to suppose that they came from a greater height than these clouds.

5. Most of them were seen to move with a very rapid motion; and of those on the velocity of which observations have been made, that is said to have moved quickest which was seen in the month of November, 1758; and which, according to the calculation of Sir John Pringle§, passed over thirty English or seven German miles in one second; a velocity greater by $3\frac{1}{2}$ miles in a second, than that of the earth in its orbit. The one said to have moved slowest is that which was seen by Balbus at Bologna, in the month of March, 1719‖, and which proceeded, according to his reckoning, at about

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* Forster's Observations on Physical Geography, made during a voyage round the world, &c. p. 119.

† Breslauer Sammlungen von Natur-und Medicin-Geschichten. III. Jan. 1716, p. 544. Hanov. Magazin, 1791, p. 1628.

‡ Breslauer Sammlungen xxix. Aug. 1724, p. 169. Compare Lichtenberg's Gothaisches Magazin, vol. iii. part 2, p. 92; vol. iv. part 2, p. 164.

§ Philosoph. Transactions, vol. li. part 1, p. 218.

‖ De Bonon. Scient. Instit. Comment. vol. i. p. 285.

1530 feet, or 0,067 of a German mile in a second. But there is reason to conclude that the movement of others*, the course of which, as might be conjectured from their long train, was not in the direction of the eye, must have been much slower. Some appear also, unless these be refused a place here, to be peculiar to one part of the heavens†.

6. They proceed from, as well as towards, all points of the compass. The greater part of them, however, have beyond all dispute appeared in the northern or southern parts of the horizon; but no general conclusion, in regard to their connexion with the northern ‡ or southern lights, can be drawn from this circumstance; though some observations made in Sweden § seem to favour such an hypothesis.

7. They do not always move according to the direction of the wind. The third observed by Ulloa makes, perhaps accidentally, an exception; and the spindle-shaped meteor seen by M. Lichtenberg, at Gottingen, on the 12th of November ||, was towards the S. S. E. the then direction of the wind, which however near the earth, was very little felt. Besides, their velocity was seldom, or never, proportioned to that of the wind; as during the most violent storm it does not move above 100 feet per second. When such meteors have appeared, it has been generally calm; but some of them were followed by wind ¶; and Forster observed that after each fire-ball which he saw, a violent wind took place.

8. They almost all fell towards the earth, and consequently from a rarer to a denser atmosphere, as in most cases might be concluded from their soon becoming considerably enlarged. Some of them, however, particularly those which moved slowly, seemed to proceed in a horizontal direction over the surface of the earth; but

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* Breslauer Sammlungen, iv. May 1718, p. 1777; Phil. Trans. vol. xliii. No. 477, p. 524; and Gothaisches Magazin, vol. iv. part 2, p. 164.

† Hof in Acta Litteraria et Scient. Sueciæ, an. 1734, p. 78; and De Genssance in Histoire de l'Acad. des Sciences. Paris 1738. p. 36.

‡ Bergman's Physic. Beschreibung der Erdkugel, vol. ii. p. 78. Bernstoff in Rozier's Journal de Physique, 1784, p. 115; and Blagden in the Phil. Trans. for 1784, p. 229.

§ Hof and Celsius in Acta Litteraria et Scient. Sueciæ, an 1734, p. 78 and 81. Gisler in Schwedische Abhandlungen, vol. xxv. p. 65.

|| Hannövrisches Magazin, 1791, p. 1626.

¶ Acta Litteraria Sueciæ, 1734, p. 78; and Chladni in Gothaisches Magazin, vol. xi. part 2, p. 712.

none of them, according to every appearance, moved upwards. Their motion, therefore, cannot be explained in the same manner as that of sky-rockets*, where the superior air is rarefied by the flame, and that below condensed.

9. Their form was sometimes perfectly globular, and sometimes more spindle-shaped; so that their length often occupied seven or eight degrees of the heavens. When observed to move with great velocity, they had a long tail behind, which arose chiefly from the continuance of the impression made on the eye†. Others, however ‡, and particularly those which moved slowly, shewed that a part of the tail belonged to the body itself; and it would appear that the long train which marks their course, ought often to be explained rather by traces left behind them than by mere impression §.

10. Their apparent magnitude was very different, but on several occasions greater than that of the moon ||.

11. Only a few of them had an apparent motion round their axis ¶.

12. The greater part of them diffused a very lively dazzling light**; the fewer number a faint light. Their colour and splendour were very different and variable; sometimes red, sometimes blue, sometimes violet, sometimes in part yellow or dazzling white, and some exhibited the prismatic colours††. Several have been

* Gothaisches Magazin, vol. iii. part 2, p. 95.

† Intelligimus magis qua apparent stella, quam qua eat. Itaque velut igne continuo totum iter signat, quia visus nostri tarditas non subsequitur momenta currentis, sed videt simul et unde exsilierit et quo pervenerit. Quod fit in fulmine, longus nobis videtur ignis ejus, quia cito spacium suum transilit, et oculis nostris occurrit universum, per quod dejectus est. At ille non est extenti corporis per omne qua venit. Senecæ Quest. Natur. lib. i. cap. xiv.

‡ Robinson in the Phil. Trans. for 1784, part i. p. 225.

§ Breslauer Sammlungen, i. 1717, p. 157; Phil. Trans. vol. xli. part 2. p. 870, vol. xlii. p. 1; and Transactions of the American Phil. Society, vol. ii. p. 173.

|| Histoire de l'Acad. des Science. Paris, 1761, p. 28. Gothaisches Magazin, vol. iii. part ii. p. 92.

¶ Nova Acta Nat. Curios. vol. i. p. 348. Theorie der am 23sten Jul. 1762 erschienenen Feuerkugel von J. E. Silberschlag. Magd. Stend. u. Leipz. 1764. 4.

** Phil. Trans. vol. xlii. part 1, p. 346.

†† Gothaisches Magazin, vol iv. part 2, p. 164. Hannovrisches Magazin, 1791, p. 1627.

seen to burn with a bright flame, and others as if in a state of ignition.

13. Their real diameter, as far as could be ascertained, sometimes by conjecture and sometimes by actual measurement, was always very considerable. The diameter of that respecting which Sir John Pringle made calculations from various observations he collected, and of that seen by Mr. Rittenhouse* at Philadelphia, in the month of October, 1779, were at most about half a German mile.

14. They seem to have originated at a very different, though most of them at a very considerable height above the surface of the earth. At any rate all of them, whose mean or greatest height was subjected to any calculation, exceeded that of the highest clouds, as clouds are scarcely perceptible at the height of 13,500 toises; and Silberschlag found the greatest height of the fire-ball, which appeared in July, 1762, to be 19 German miles, or 72,276 toises. On this account their origin, as Reimarus and Chladni have already sufficiently shewn, is not to be ascribed merely to electricity, though some have considered them as occasioned by the action of the electric fluid between the clouds and the northern lights, which would agree exceedingly well with their actual height; as, according to the measurement of Bergman, Kastner and Lambert†, the northern lights have an altitude of more than 20 or 30 German miles, and according to every appearance no fire-balls have been seen higher. On the other hand, this general conclusion led Halley ‡, Franklin§, and Rittenhouse ||, to the grand idea, which Dr. Chladni has defended with so much ingenuity, that these phænomena, as well as shooting stars, are cosmical meteors belonging to the atmosphere of the sun, which meeting our earth in its course round that luminary, are inflamed, by some cause or other, when they enter the earth's atmosphere. The phenomenon also seen by De Genssance at Paris, in the month of July, 1738, and the like observation of falling stars on the highest mountains, as well as on the surface of

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* Transactions of the American Philosoph. Society, vol. ii. p. 175.

† Gottingischer Taschen-Calendar, 1778, p. 52.

‡ Philosoph. Transactions, No. 341.

§ Gothaisches Magazin, vol. iv. part 2, p. 114; and vol. ix. part 3, p. 173.

|| Transactions of the American Philosoph. Society, vol. ii. p. 175.

the sea*; but in particular the new distant luminous phenomenon observed by M. Schroter †, will appear the more favourable to this hypothesis, as we have reason to suppose that there are processes carried on in our atmosphere with which we are as little acquainted as with those carried on in the interior parts of the earth.

15. The time of their duration was very different: that observed by De Genssance continued half an hour; at other times their duration has seldom been above a minute. Few or none of them, however, have been observed from the commencement of their appearance till the time when they disappeared.

16. Many of them in their course threw out sparks, and the greater part of them were seen to divide themselves into several, sometimes larger, sometimes smaller parts, before they entirely disappeared. This division also seems to oppose the hypothesis of a track of inflammable air set on fire ‡, which Dr. Chladni has sufficiently refuted on other grounds.

17. This bursting into pieces was for the most part accompanied with a rumbling noise like thunder, or a sudden report. This was observed to be the case in regard to 27 of the 50 above-mentioned; and very often two or more reports have been heard in succession, without the large ball being divided into smaller ones, and without these being still farther shattered. But as these reports were heard at a very great distance §, and as many which did not appear to be more remote, but nearer, have burst without any report; a question arises, whether we are to consider, as Dr. Chladni does, this violent bursting as peculiar to all these phænomena?

18. Several, after bursting, seemed to dissolve into smoke ||, and, according to the observation made by Celsius in the month of March, 1731, a visible smoking stripe seemed to be previously inflamed. The greater part of them, however, after exploding, left no visible traces behind.

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* Brydone in the Philosoph. Transactions, vol. lxiii. part 1, p. 167.

† Gothaisches Magazin, vol. xi. part 1, p. 86.

‡ Gehlers Phys. Wörterbuch, art. Feuerkugel.

§ Allgem. Historie der Reisen, vol. ix. p. 564; and Philosoph. Transactions, vol. iii. part 1, p. 163.

|| De Bonon. Scient. Institut. Comment. vol. i. p. 285; Philosoph. Transactions, vol. xli. part 2, p. 870, vol. xlii. p. 1; and Hist. de l'Acad. des Sciences, Paris, 1753, p. 73.

19. In some cases, after their disappearance, a sulphureous smell was perceived *, like that perceived after lightning has fallen, and which gave occasion to Muschenbroek's hypothesis of an accumulation of sulphureous inflammable vapours that arise from volcanoes and subterranean pits, and being driven together by the winds, form clouds, that by some accident or other are set on fire; but which, however, can as little be reconciled with their general prodigious height, as Silberschlag's oily and slimy vapours.

20. As scoriaceous masses have frequently been either actually seen to fall at the time of the disappearance of these phænomena, or have been found soon after on the surface of the earth; and as it is sufficiently proved by various accounts that stones have fallen from the atmosphere, Dr. Chladni concludes that both these phænomena are connected; but this can be determined only by future accurate observations.

[*Good's Lucretius. Thomson's Chemistry.*

SECTION IX.

Aërolites, or Meteoric Stones.

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1. *General History and Observations.*

It is now well known, and admitted without hesitation, that a variety of stony bodies are frequently falling from the atmosphere, in every quarter of the world, and in every instance of similar composition, and connected with the fiery meteors we have just contemplated. It is not many years ago, however, that the fact was generally discredited by every one. Yet it is by no means a discovery of modern times, having been almost as fully known to the philosophers of Greece as it is at present to the philosophers of Europe at large.

"What," observes a writer who is well acquainted with their opinions, "will the unlearned reader say, when he finds that even the meteoric stones, or those which are now traced to have fallen from the heavens, and are at this moment, for the first time, as is

* Breslauer Sammlungen, i. p. 157; Philosoph. Transactions, vol. 1. p. 299; and Goth. Magazin, vol. xi. part 2, p. 112.

commonly supposed, exciting attention in the philosophic world, are not a new discovery, and were known to mankind upwards of four hundred years before the birth of our Saviour; were as differently accounted for by the sages of that early æra as they are in our own day; and their fall *capable of being foretold* by some of them, and especially by Anaxagoras, who predicted the descent of a very large stone, that fell accordingly on the banks of the Argos, in Thrace. This fact and prediction are recorded by Pliny ii. 68, and Diogenes and Laertius, in Vit. Anaxag. ii. 10. Aristotle, in his first book of Meteorics, supposes these stones to be carried upwards from the earth in the course of a violent tempest. In modern times they are said by many philosophers to fall from the *moon*. Anaxagoras contended that they fell from the *sun*: and hence his disciple Euripides denominates the sun χρυσεον βωλον, "a golden-glebe *."

But though, observes Dr. Thomson, several well-authenticated accounts of the fall of such stones had been from time to time published, little credit was given to them; nor did they indeed attract the attention of philosophers, till Dr. Chladni published a dissertation on the subject, in 1794. Two years after, Mr. King published a still more complete collection of examples, both ancient and modern; many of them supported by such evidence that it was impossible to reject it. These two dissertations excited considerable attention: but the opinion, that stones had really fallen from the atmosphere, was considered as so extraordinary, and so contrary to what we know of the constitution of the air, that most people hesitated, or refused their assent. Meanwhile Mr. Howard took a different method of investigating the subject. He not only collected all the recent and well-authenticated accounts of the fall of stony bodies, and examined the evidence of their truth, but procured specimens of the stones which were said to have fallen in different places, compared them together, and subjected them to a chemical analysis. The result was, that all these stony bodies differ completely from every other known stone; that they all resemble each other, and that they are all composed of the same ingredients. His dissertation on the subject was published in the Philosophical Transactions for 1802. The proofs which this admirable disserta-

* Good's Notes to his Translation of Lucretius, book iii. c. 239, p. 414.

tion contains, that the stony bodies in question really fell from the atmosphere, are quite irresistible. Indeed their external characters and chemical analysis would alone decide the point: For it is quite inconceivable that in India, England, France, Germany, and Italy, in climates and in soils exceedingly different from each other, stones should have been pointed out which differed from every other mineral in the countries where they were found, and which exactly resembled one another, provided those had not had the same origin. The chemical analysis of Howard was soon after repeated and verified by Vauquelin* and Klaporth†.

1. Most of the stones which have fallen from the atmosphere have been preceded by the appearance of luminous bodies or meteors. These meteors burst with an explosion, and then the shower of stones falls to the earth. Sometimes the stones continue luminous till they sink into the earth; but most commonly their luminousness disappears at the time of the explosion. These meteors move in a direction nearly horizontal, and they seem to approach the earth before they explode. The following Table, drawn up by Mr. Izarn, exhibits a collection of the best-authenticated instances of the falling of stones from the atmosphere hitherto observed, together with the time when they fell, and the persons on whose evidence the fact rests ‡.

* Ann. de Chim. xlv. 225. † Phil. Mag. xv. 182. ‡ Ibid. xvi. 298.

Substances.	*Places where they Fell.*	*Period of their Fall.*	*Testimony.*
Shower of Stones	At Rome	Under Tullus Hostilius	Livy.
Shower of Stones	At Rome	Consuls C. Martius and M. Torquatus	J. Obsequens.
Shower of Iron	In Lucania	Year before the defeat of Crassus	Pliny.
Shower of Mercury	In Italy		Dion.
A very large Stone	Near the River Negos, Thrace	Second year of the 78th Olympiad	Pliny.
Three large Stones	In Thrace	Year before J. C. 452	Ch. of Count Marcellin.
Shower of Fire	At Quesnoy	January 4th, 1717	Geoffroy le Cadet.
Stone of 72lbs.	Near Larissa, Macedonia	January, 1706	Paul Lucas.
About 1200 Stones—one of 120 lbs. Another of 60 lbs.	Near Padua, in Italy	In 1510	Carden, Varcit.
Another of 59 lbs.	On Mount Vasier, Provence	November 27th, 1627	Gassendi.
Shower of Sand for fifteen hours	In the Atlantic	April 6th, 1719	Pere la Fuillée.
Shower of Sulphur	Sodom and Gomorrah		Moses.
Sulphureous Rain	In the Duchy of Mansfield	In 1658	Spangenberg.
The same	Copenhagen	In 1646	Olaus Wormius.
Shower of Sulphur	Brunswick	October, 1721	Siegesbœr.
Ditto of a viscid unknown matter	Ireland	In 1695	Muschenbroeck.
Two large Stones, weighing 20 lbs.	Liponas in Bresse	September, 1753	Delalande.
A Stony Mass	Niort, Normandy	In 1750	Delalande.
A Stone of 7½ lbs.	At Luce in Le Maine	September 13th, 1768	Bachelay.
A Stone	At Aire in Artois	In 1768	Gurson de Boyaval.
A Stone	In Le Cotentin	In 1768	Morand.
Extensive Shower of Stones	Environs of Agen	July 24th, 1790	St. Amand, Baudin, &c.
About twelve Stones	Sienna, Tuscany	July, 1794	Earl of Bristol.
A large Stone of 56 lbs.	Wold Cottage, Yorkshire	December 13th, 1795	Captain Topham.
A Stone of about 20 lbs.	Salé, Department of the Rhone	March 17th, 1798	Lelievre and De Drée.
A Stone of 10 lbs.	In Portugal	February 19th, 1796	Southey.
Shower of Stones	Benares, East Indies	December 19th, 1798	J. Lloyd Williams, Esq.
Shower of Stones	At Plann, near Tabor, Bohemia	July 3d, 1753	B. de Born.
Mass of Iron 70 cubic feet	America	April 5th, 1800	Philosophical Magazine.
Mass of ditto 14 quintals	Abakank, Siberia	Very old	Pallas, Chladni, &c.
Shower of Stones	Barboutan, near Roquefort	July, 1789	Darcet, Jun. Lomet, &c.
Large Stone of 260 lbs.	Enisheim, Upper Rhine	November 7th, 1492	Butenschoen.
Two Stones 200 and 300 lbs.	Near Verona	In 1762	Acad. de Bourd.
A Stone of 20 lbs.	Sales, near Ville Franche	March 12th, 1798	De Drée.
Several ditto from 10 to 17 lbs.	Near L'Aigle, Normandy	April 26th, 1803	Fourcroy.

2. The stony bodies when found are always hot. They commonly bury themselves some depth under ground. Their size differs from a very few ounces to several tons. They are usually roundish, and always covered with a black crust. In many cases they smell strongly of sulphur. The black crust, from the analysis of Howard, consists chiefly of oxide of iron.

3. The outer surface of these stones is rough. When broken, they appear of an ash-grey colour, and of a granular texture, like a coarse sandstone. When examined with a microscope, four different substances may be discovered of which the stone is composed: 1st, A number of spherical bodies, varying in size from a pin-head to a pea of a greyish-brown colour, opaque, breaking easily in every direction, of a compact texture, capable of scratching glass, and of giving a few feeble sparks with steel. 2d. Fragments of pyrites of an indeterminate shape, of a reddish-yellow colour, granular, and easily reduced to powder. The powder has a black colour. 3d. Grains of iron in the metallic state, scattered like the pyrites through the stone. 4th. The three substances just mentioned are cemented together by a fourth of an earthy consistence, and so soft that all the other substances may be easily separated by the point of a knife or the nail, and the stone itself crumbled to pieces between the fingers. This cement is of a grey colour*. The proportion and size of these different constituents vary considerably in different specimens; but all of them bear a striking resemblance to each other. Their specific gravity varies from 3·352 to 4·281 †.

4. From the analysis of Howard, which was conducted with much precision and address, and which has been fully confirmed by Vauquelin and Klaproth, we learn that the black crust consists of a compound of iron and nickel, partly metallic, and partly oxidized. The pyrites consist of iron, nickel, and sulphur. The metallic grains consist of iron, combined with about 1-3d of its weight of nickel, and the yellow globules are composed of silica, magnesia, iron, and nickel. The Count Bournon observes, that these globules resembles the chrysolite of Werner, and that their chemical analysis corresponds exactly with Klaproth's analysis of that mineral. The earthy cement consists of the very same substances, and

* Bournon, Phil. Trans. 1809. † Ibid.

nearly in the same proportion as the globular substances. But it will be necessary to exhibit a specimen of some of the analysis, as published by the philosophers to whom we are indebted for them. A stone which fell at Benares in India was analysed by Howard. The pyrites consisted of

2·0	sulphur
10·5	iron
1·0	nickel
2·0	earths and foreign bodies
15·5	

The spherical bodies	50·0	silica
	15·0	magnesia
	34·0	oxide of iron
	2·5	oxide of nickel
	101·5	

The earthy cement	48·0	silica
	18·0	magnesia
	34·0	oxide of iron
	2·5	oxide of nickel
	102·5	

A stone which fell in Yorkshire, deprived as much as possible of its metallic particles, gave Mr. Howard from

150 grains.........	75	silica
	37	magnesia
	48	oxide of iron
	2	oxide of nickel
	162	

The increase of weight was owing to the oxidizement of the metallic bodies.

Stones which fell at Laigle in France, in 1803, yielded by the analyses of Vauquelin and Fourcroy,

54 silica
36 oxide of iron
9 magnesia
3 oxide of nickel
2 sulphur
1 lime

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The following Table exhibits the result of the most remarkable analyses of such stones, which have been made since the publication of Howard's paper on the subject.

	†	‡	‖	§	¶
Iron		2·25	19·0	38·3	17 to 22
Nickel	2·4	0·60	1·5	0·33	
Oxide of iron	30·0	25·00	16·5		5
Sulphuret of iron					12
Sulphur	3·5	Trace	Trace	9·00	
Silica	56·0	44·00	37·0	34·00	
Magnesia	12·0	22·50	21·5	14·50	66
Lime	1·4				Trace
Manganese		0·25		0·83	

5. The experiments of Howard, thus confirmed by others, and supported by the most respectable historical evidence, having demonstrated that these stony bodies really do fall from the heavens, it was natural to expect that various attempts would be made to account for their appearance. But such is the obscurity of the subject, so little progress have we made in the science of meteorology, that no opinion in the slightest degree probable has hitherto

* Phil. Mag. xvi. 302.

† Vauquelin, Phil. Mag. xvi. 302. The stone fell at Ensisheim, in 1492.

‡ Klaproth, Gehlen's Jour. i. 8. The stone fell at Sienna, in 1794.

‖ Klaproth, Ibid. p. 19. The stone fell at Auchstadtschen, in Germany.

§ Laugier, Ibid iv. 531. The stone fell at Vaucluse in 1804. See a description of it by Vauquelin, Ann. de Chim. xlviii. 225.

¶ Proust, Jour. de Phys. xl. 185. The stone fell at Sigena, in 1773.

been advanced. It was first supposed that the bodies in question had been thrown out of volcanoes: but the immense distance from all volcanoes at which they have been found, and the absence of all similar stones from volcanic productions, render this opinion untenable. Chladni endeavoured to prove that the meteors from which they fell were bodies floating in space, unconnected with any planetary system, attracted by the earth in their progress, and kindled by their rapid motion through the atmosphere. But this opinion is not susceptible of any direct evidence, and can scarcely be believed, one would think, even by Dr. Chladni himself. La Place suggests the probability of their having been thrown off by the volcanoes of the moon: But the meteors which almost always accompany them, and the swiftness of their horizontal motion, militate too strongly against this opinion. The greatest number of philosophers consider them, with Mr. King and Sir William Hamilton, as concretions actually formed in the atmosphere. This opinion is undoubtedly the most probable of all; but in the present state of our knowledge, it would be absurd to attempt any explanation of the manner in which they are formed. The masses of native iron found in South America, in Siberia, and near Agnam, contain nickel, as has been ascertained by Proust, Howard, and Klaproth, and resemble exactly the iron found in the stones fallen from the atmosphere. We have every reason therefore to ascribe to them the same original: and this accordingly is almost the uniform opinion of philosophers. Klaproth hath shown that real native iron is distinguished from meteoric iron by the absence of nickel *.

[*Good's Lucretius. Thomson's Chemistry.*

2. *Lunar or Selenitic Origin of Meteoric Stones.*

The best and fullest examination which has yet occurred to us upon this curious subject, is contained in a long and interesting original note of the Editors of the "Philosophical Transactions Abridged," appended to Dr. Halley's paper on Meteors, or lights

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* Gehlen's Jour. i. 8.

This closing remark is a strong proof of the difference between the two, and the article which immediately follows is sufficient to show that the ingenious chemist is in an error, in conceiving that the hypothesis to which he seems to incline is "almost the uniform opinion of philosophers."

[Editor.

in the sky, published in vol. xxix. of the Transactions at large. The note is as follows:

Dr. Halley's mind fixes on nothing but vapour or exhalations, to solve the appearance; though the difficulty, not to say impossibility, of conceiving how any exhalations could be raised so high, ought to have hinted the idea of some other origin. Later observations however have induced a belief, that these luminous appearances are allied to, if not the same as, the stones which have frequently been known to fall from the atmosphere, at different times, and in all parts of the earth. Several of the phænomena are common to both. These luminous bodies are seen to move with very great velocities, in oblique directions descending; commonly with a loud hissing noise, resembling that of a mortar-shell, or cannon-ball, or rather that of an irregular hard mass projected violently through the air; surrounded by a blaze or flame, tapering off to a narrow stream in the hinder part of it; are heard to explode or burst, and seen to fly in pieces, the larger parts going foremost, and the smaller following in succession; are thus seen to fall on the earth, and strike it with great violence; that on examining the place of the fall, the parts are found scattered about, being still considerably warm, and most of them entered the earth several inches deep. After so many facts and concurring circumstances, it is difficult to refuse assent to the identity of the two phænomena: indeed it seems now not to be doubted, but generally acquiesced in. And hence it is concluded, that every such meteor-like appearance is attended by the fall of a stone, or of stones, though we do not always see the place of the fall, nor discover the stones.

This conclusion, however, has contributed nothing towards discovering the origin of the phenomenon, at least as to its generation in the atmosphere: on the contrary, it seems still more difficult to account for the production of stones, than gaseous meteors, in the atmosphere, as well as to inflame and give them such violent motion. In fact, it seems concluded as a thing impossible to be done, or conceived; and philosophers have given up the idea as hopeless. This circumstance has induced them to endeavour to discover some other cause or origin for these phænomena. But no idea that is probable, or even possible, has yet been started; excepting one, by the very celebrated mathematician La Place, and

that of so extraordinary a nature, as to astonish us with its novelty and boldness of conception. This is no less than the conjecture, that these stony masses are projected from the moon! a conjecture which none but an astronomer could have made, or at least have shown to be probable, or even possible. Any ordinary person might at random utter the vague expression of a thing coming from the moon: but no one, except the philosopher, could propose the conjecture seriously, and prove its possibility. This M. La Place has been enabled to do by strict mathematical calculation. He has proved that a mass, if projected by a volcano from the moon, with a certain velocity, of about a mile and a half per second, (which is possible to be done) it will thence be thrown beyond the sphere of the moon's attraction, and into the confines of the earth's; the consequence of which is, that the mass must presently fall to the earth, and become a part of it.

To prepare the way for a calculation, and a comparison of this supposed cause with the phænomena, it will be useful here to premise a short account of the late and best-observed circumstances in the appearance of fire-balls, and the fall of stony masses from the atmosphere, extracted from the last published accounts of some of the more remarkable cases.

It is remarkable how generally the tradition has prevailed, in almost all ages, and among all people, of the fall of solid materials from the atmosphere, under the various denominations of thunderbolts, showers of stones, masses of native iron, &c. generally believed by the common people, who had often witnessed the fact, as coming from the sky or the heavens, and thence ascribed to the miraculous judgments of the Deity; while they were as generally disbelieved by the philosophers, either because they had never seen them fall, or because they found it impossible to account for the cause of them.

In the later ages of the world, however, the fact has been observed by more respectable evidences, and recorded with circumstances of considerable accuracy. One instance of this kind is that given by the celebrated astronomer Gassendi, who was an eyewitness of what he relates. November 27, 1627, the sky being quite clear, he saw a burning stone fall on mount Vaisir, in the south-east extremity of France, near the city of Nice, on the coast of the Mediterranean Sea. While in the air, it seemed to be

about four feet in diameter; it was inclosed in a luminous circle of colours like a rainbow; and in its fall it produced a sound like the discharge of cannon. It weighed 59lb., was very hard, of a dull metallic colour, and in specific gravity considerably more than that of marble.

Prior to this is another remarkable instance in the stone that fell near Ensisheim, a considerable town in Alsace, the north-east point of France, near the upper Rhine, a little north of Basil. This was in 1492, November 7, between eleven and twelve before noon, when a dreadful thunder-clap was heard at Ensisheim, and a child saw a huge stone fall on a field lately sowed with wheat. On the people going to the place, the hole was found, and digging out the stone, it was found to have entered three feet deep, and weighed 260lb., which makes its size equal to a cube of about thirteen inches the side. No doubt has ever been entertained of this fact; and cotemporary writers all agree in its general belief by the neighbourhood, and the natives of the place must have known that in their wheat field no such stone or hole had formerly existed.

In the year 1672, two stones fell near Verona, in Italy, the one weighing 300, the other 200lb. Soon after, one of the members of the Abbé Bourdelot's academy presented, at one of their meetings, a specimen of these two stones; stating, that the phenomenon had been seen by 300 or 400 persons; that the stones fell in a sloping direction, during the night, and in calm weather; that they appeared to burn, fell with great noise, and ploughed up the ground.—It is a pity the record does not mention the bearing of their path, as to the point of the compass.

It is related by Paul Lucas, the traveller, that when he was at Larissa, a town in Greece, near the gulph of Salonica, a stone of 72lb. weight fell in the neighbourhood. It was observed to come from the northward, with a loud hissing noise, and seemed to be enveloped in a small cloud, which exploded when the stone fell. It looked like iron dross, and smelled of sulphur.

In September, 1753, several stones fell, accompanied with loud noises, in the province of Bresse, a little west from Geneva; particularly one fell at Pont-de-Vesle, and one at Liponas, at nine miles distance from each other. The sky was clear, and the weather warm. A loud noise and hissing sound were heard at those two places, and for many miles round, at the time the stones fell.

The stones appeared exactly similar to each other, of a darkish dull colour, very heavy, and their surface showing as if they had suffered a violent degree of heat. The largest weighed about 20lb., and penetrated about six inches into the ploughed ground, a circumstance which renders it highly improbable that they could have existed there before the explosion. This phenomenon has been described by the astronomer Delalande, who seems to have carefully examined, on the spot, the truth of the circumstances he describes.

In the year 1768, three stones were presented to the Academy of Sciences at Paris, which had fallen in different parts of France; one at Lucé, in the Maine; another at Aire, in Artois; and the third in Cotentin. These were all externally of the very same appearance; and Messrs. Fougeraux, Cadet, and Lavoisiér, drew up a particular report on the first of them. They state, that on the 18th of September, 1768, between four and five, afternoon, there was seen near the village of Lucé, in Le Maine, a cloud, in which a short explosion took place, followed by a hissing noise, but without any flame; that some persons about ten miles from Lucé heard the same sound; looking upwards, they perceived an opaque body describing a curve line in the air, and fall on a piece of green turf near the high road; that they immediately ran to this place, where they found a kind of stone, half buried in the earth, extremely hot, and weighing about 7½lb.

July 24, 1790, between nine and ten at night, a shower of stones fell near Agen, in Guienne, near the south-west angle of France. First, a luminous ball of fire was seen, traversing the atmosphere with great rapidity, and leaving behind it a train of light which lasted about fifty seconds; soon a loud explosion was heard, and sparks were seen flying off in all directions. This was soon after followed by the fall of stones, over a considerable extent of ground, and at various distances from each other. These were all alike in appearance, but of many different sizes, the greater number weighing about two ounces, but many a vast deal more: some fell with a hissing noise, and entered the ground, but the smaller ones remained on the surface. The shower did no considerable damage, only breaking the tiles of some houses. All this was attested in a process-verbal, signed by the magistrates of the municipality: it was further substantiated by the testimony of

several hundred persons, inhabitants of the place; and several learned men wrote the very same account to their scientific correspondents; one of those (son of the celebrated chemist M. D'Arcet) mentions two additional and important circumstances, from his own observation: viz. that the stones, when they fell on the houses, had not the sound of hard and compact substances, but of a matter in a soft, half-melted state; and that such of them as fell upon straws adhered to them, so as not to be easily separated. That these stones broke the roofs of houses, and were found with pieces of straw under, and adhering to them, is a clear proof of their falling from above, and in a state of fusion.

December 18, 1795, several persons, near Captain Topham's house, in Yorkshire, heard a loud noise in the air, followed by a hissing sound, and soon after felt a shock, as if a heavy body had fallen to the ground at a little distance from them: in fact, one of them saw a huge stone fall to the earth, at eight or nine yards from the place where he stood; it was seven or eight yards above the ground when he first observed it: in its fall it threw up the mould on every side, and buried itself twenty-one inches deep: the stone, being raised, was found to weigh 56 lb.

March the 17th, 1798, a body, burning very brightly, passed over the vicinity of Ville Franche, on the Saone, a little to the east of Lyons, in France, accompanied with a hissing noise, and leaving a luminous track behind it. This phenomenon exploded with a great noise, about 1200 feet from the ground; and one of the splinters, still luminous, being observed to fall in a neighbouring vineyard, was traced: at the spot a stone was found, about a foot diameter, which had penetrated twenty inches into the ground.

While these circumstances in Europe were daily confirming the original, but long exploded idea of the vulgar, that many of the luminous meteors observed in the atmosphere, are masses of ignited matter, an account of a phenomenon, of precisely the same description, was received from the East Indies, vouched by authority particularly well adapted to procure general respect. Mr. Williams, F.R.S. residing in Bengal, hearing of an explosion, with a descent of stones, in the province of Bahar, diligently enquired into the circumstances, among the Europeans on the spot. He learned, that on December 19, 1798, at eight o'clock in the evening, a large fire ball, or luminous meteor, was seen at Benares,

and other parts of the country: that it was attended with a loud rumbling noise; and that, about the same time, the inhabitants of Krakhut, fourteen miles from Benares, saw the light, heard like a loud thunder-clap, and immediately after heard the noise of heavy bodies falling in the neighbourhood. Next morning the mould in the fields was found to have been turned up in many spots; and unusual stones of various sizes, but of the same substances, were picked out of the moist soil, generally from a depth of six inches. As the occurrence took place in the night, after the people had retired to rest, the explosion and the fall of the stones were not seen: but the watchman of an English gentleman, near Krakhut, brought him a stone the next morning, which he said had fallen through the top of his hut, and buried itself in the earthen floor.

Several of the preceding accounts notice the material circumstance of damage done to interposed objects by the falling stones. In one instance, not yet mentioned, still more distinct traces were left, to show that their progress was through the air: viz. during the explosion of a meteor near Bourdeaux, the 20th of August 1789, a stone, about fifteen inches diameter, fell through the roof of a cottage, and killed a herdsman and some cattle. Part of this stone is now in the Museum of the Right Honorable Charles Greville, and the rest in that of Bourdeaux. See Mr. Greville's paper in the Phil. Trans. for 1803, pt. 1.

Hence it seems quite impossible to deny very great weight to all these testimonies, and many others that might be given; several of them by intelligent eye-witnesses, and others by more ordinary persons indeed, but prepossessed by no theory; all concurring in their descriptions; and examined by acute and respectable persons, immediately after the phænomena had occurred. Without offering any further remarks then, on this mass of external evidence, we shall only just notice the main points, which it seems to substantiate in a very satisfactory manner. It proves then, that, in various parts of the world, luminous meteors have been seen moving through the air with surprising rapidity, in a direction more or less oblique, accompanied with a noise, commonly like the whizzing of large shot, followed by explosion, and the fall of hard, stony, or semi-metallic masses, in a heated state. The constant whizzing sound; the fact of stones being found, similar to each

other, but unlike all others in the neighbourhood, at the spots towards which the luminous body or its fragments were seen to move; the scattering or ploughing up of the soil at those spots, always in proportion to the size of the stones; the concussion of the neighbouring ground at the time; and especially the impinging of the stones on bodies somewhat above the earth, or lying loose on its surface—are circumstances perfectly well authenticated in these reports; proving that such meteors are usually inflamed hard masses, descending rapidly through the air to the earth.

Having drawn this conclusion from the consideration of the more plain and obvious circumstances of these stones and meteors; we may now advert to those of the more close and intimate examination of the stones themselves: and this we find at once strengthening the foregoing conclusion, and conducting to a further knowledge of the subject, than is afforded by the mere external evidence only.

The reports of all those persons who saw and observed the meteors, and found the stones in the several places, after the explosions, uniformly agree, in describing those substances as different from all the neighbouring bodies, and as presenting, in every case, the same external appearance of semi-metallic matter, coated on the outside with a thin black crust, and bearing strong marks of recent fusion. Besides this general resemblance, obvious to the most ordinary inspection, many of those singular substances have been most carefully examined by some of the first chemists and naturalists of the age, and their investigations have put us in possession of a mass of information, sufficient to convince the most scrupulous inquirer, that the bodies in question have a common origin, and that we are totally unacquainted with any natural process which could have formed them on our globe.

The more nice and chemical examination of those stones has been made by Messrs. De la Lande, Lavoisier, Fougeraux, Cadet, Vauquelin, Barthold, Count de Bournon, our learned countryman, Mr. Howard, and several other ingenious men; and all their reports agree in representing them of a similar nature and composition, formed of the same simple materials, of nearly the same specific weight, and with very slight variations in the proportions of the component parts, forming the aggregate of these masses. Mr. Howard and the Count de Bournon found that the specific

gravities of all the stones were nearly the same, excepting that the greater abundance of iron in one of them caused a considerable increase in its gravity.

From their researches it appears, that the specific gravities of some of the more remarkable stones, are as in the annexed Table, considering 1000 as the proportionate number for the specific gravity of water. From whence it appears, that in this respect they greatly exceed all the known ordinary stones, and approach to those of the metallic ores.

	Spec. Grav.
The Enisheim Stone	3233
Benares	3352
Sienna	3418
Gassendi's	3456
Yorkshire	3508
Bachelay's	3535
Bohemia	4281

All the stones examined by Count de Bournon and Mr. Howard were found to consist of four distinct substances, viz. small metallic particles, a peculiar martial pyrites, a number of globular and elliptical bodies, also of a peculiar nature, and an earthy cement surrounding the other component parts. The nature of the metallic particles was the same in all, being in each an alloy of iron and nickel. In the pyrites, nickel as well as iron was detected; and the easy decomposition of the pyrites, by muriatic acid, afforded a distinguishing character of that substance. The globules contained silica, magnesia, and oxides of nickel and iron. The earthy cement consisted of the same substances, very nearly in the same proportions.

M. Vauquelin also, about the same time as Mr. Howard, analysed the Benares stones, and two others which fell in 1789 and 1790, in the south of France; and the results of his experiments agreed with those of Mr. Howard in every particular. So that we are now authorised to conclude, that the stones which have at different times fallen down on the earth, in England, France, Italy, and India, are exactly of the same nature, consisting of the same simple substances arranged in similar compounds, in nearly the same proportions, and in the same manner combined, so as to form heterogeneous aggregates, whose general resemblance to each other is complete. We are hence also warranted in another important inference, viz. that no other bodies have as yet been discovered on our globe, which contain the same ingredients; and

that the analysis of these stones has brought us acquainted with a species of pyrites not formerly known, nor any where else to be found.

The general analogy between these stones, and the masses of native iron that have been found in different parts of the world, was too striking to escape the notice of the eminent inquirers who have investigated this subject. They resemble each other in their external character, though not so closely as the stones themselves; but in one circumstance of their chemical composition they have a notable similarity, both among themselves, and to the stony substances. M. Proust had before proved, that the enormous mass of native iron found in South America, contained in its composition a large portion of nickel. Mr. Howard has been led to the same conclusion by analyzing another portion of the same: and he has also found, that the like solitary masses discovered in Siberia, Bohemia, and Senegal, contained a mixture of the same metal with iron, though in various proportions. The Bohemian iron is an alloy, of which nickel forms eighteen parts in 100; in the Siberian iron it forms seventeen; and in the Senegal iron five or six. But what is still more striking, and tends to put the similarity of their origin beyond all doubt, the Siberian mass is interspersed with cavities, containing an earthy substance, of the very same nature as the earthy cement and globules of the Benares stone; and the proportions of the ingredients are also nearly alike, except only in the oxyde of iron, which is considerably less in the Siberian earth. This remarkable fact greatly strengthens the idea, that the Siberian iron owes its origin to the same causes which formed and projected the different stones that have fallen through the air on the earth; and, joined to the other details of the analysis, it naturally leads us to conclude, that the masses of native iron, as they are called, differ in no respect from the metallic particles, or the alloy of iron and nickel, which constitute one of the four aggregate parts in every stone of this kind hitherto examined.

Concerning the Siberian iron, there exists a general tradition of the Tartars, that it formerly fell from the heavens. In addition to which, a pretty authentic testimony has been lately found, to prove the fall of a similar body in India. The Right Honourable Charles Greville has communicated to the Royal Society (Phil. Trans. 1803, pt. 1) a very interesting paper, translated from the

emperor Tchangire's Memoirs of his own reign. The prince relates, that in the year 1620, of our æra, a violent explosion was heard at a village in the Punjaub, and at the same time a luminous body fell through the air on the earth. That the officer of the district immediately repaired to the spot where it was said the body fell, and having found the place to be hot, he caused it to be digged, on which he found the heat kept increasing till they reached a lump of iron violently hot. That this was sent to court, where the emperor had it weighed in his presence, and ordered it to be forged into a sabre, a knife, and a dagger; that, after trial, the workmen reported it was not malleable, but shivered under the hammer: and that it required to be mixed with one-third part of common iron, after which the mass was found to make excellent blades. The royal historian adds, that on the incident of this *iron of lightning* being manufactured, a poet presented him with a distich, that, "during his reign, the earth attained order and regularity; that raw iron fell from lightning, which was, by his world-subduing authority, converted into a dagger, a knife, and two sabres."

The exact resemblance of this occurrence, in all its essential circumstances, to the former accounts of fallen stones, and the particular remark on the unmalleable nature of the iron, give a high degree of credibility to the whole narrative, and throw additional weight on the inference before drawn from internal evidence, that the solitary masses of native iron found in different quarters of the globe, have the same origin with the stones analysed by Howard and Vauquelin.

Having now given a summary of the facts and evidence, as well with regard to the circumstances attending these singular bodies, as the ingredients they are composed of, and their outward appearance and structure, we are now to consider what inferences respecting their probable origin may be drawn from this mass of information. And indeed we may safely conclude, as it has been inferred from the whole, by the philosophers best qualified to judge of the circumstances, as follow, viz. that the bodies in question have fallen on the surface of the earth; but that they were not projected by any terrestrial volcanoes; and that we have no right, from the known laws of nature, to suppose that they were formed in the upper regions of the atmosphere. Such a negative conclusion

has been thought all that we are, in the present state of our knowledge, entitled to draw.

In this embarrassing predicament, the total want of any other possible way of accounting for the origin of those bodies, an idea has been started, perhaps at first merely at random, that since there is no other possible manner of accounting for them, then they must have dropped from the moon. And, indeed, this singular thought has now advanced into a serious hypothesis, which, it must be allowed, is unincumbered with any of the foregoing difficulties; having at least possibility in its favour, which no other hypothesis yet proposed can claim.

As the attraction of gravitation extends through the whole planetary system, a body, placed at the surface of the moon, is affected chiefly by two forces, one drawing it toward the centre of the earth, and another drawing it toward that of the moon. The latter of these forces, however, near the moon's surface, is incomparably the greater. But as we recede from the moon, and approach toward the earth, this force decreases, while the other augments, till at length a point of station is found between the two planets, where these forces are exactly equal; so that a body, placed there, must remain at rest; but if it be removed still nearer to the earth, then this planet would have the superior attraction, and the body must fall towards it. If a body then be projected from the moon towards the earth, with a force sufficient to carry it beyond this point of equal attraction, it must necessarily fall on the earth. Such then is the idea of the manner in which the bodies must be made to pass from the moon to the earth, if that can be done; the *possibility* of which is now necessary to be considered.

Now supposing a mass to be projected from the moon, in a direct line towards the earth, by a volcano, or by the production of steam by subterranean heat; and supposing for the present those two planets to remain at rest; then it has been demonstrated, on the Newtonian estimation of the moon's mass, that a force projecting the body with a velocity of 12,000 feet in a second, would be sufficient to carry it beyond the point of equal attraction. But this estimate of the moon's mass is now allowed to be much above the truth; and on M. La Place's calculation it appears, that a force of little more than half the above power would be sufficient to produce the effect; that is, a force capable of project-

ing a body with a velocity of less than a mile and a half per second. But we have known cannon balls projected by the force of gunpowder, with a velocity of 2500 feet per second, or upwards; that is, about half a mile. It follows, therefore, that a projectile force, communicating a velocity about three times that of a cannon ball, would be sufficient to throw the body from the moon beyond the point of equal attraction, and cause it to reach the earth. Now there can be little doubt that a force equal to that is exerted by volcanoes on the earth, as well as by the production of steam from subterranean heat, when we consider the huge masses of rock, so many times larger than cannon balls, thrown on such occasions to heights also so much greater. We may easily imagine, too, such cause of motion to exist in the moon, as well as in the earth; and that in a superior degree, if we may judge from the supposed symptoms of volcanoes recently observed in the moon, by the powerful tubes of Dr. Herschel: and still more, if we consider that all projections from the earth suffer an enormous resistance and diminution, by the dense atmosphere of this planet; while it has been rendered probable, from optical considerations, that the moon has little or no atmosphere at all, to give any such resistance to projectiles.

Thus then we are fully authorised in concluding, that the case of *possibility* is completely made out; that a known power exists in nature, capable of producing the foregoing effect, of detaching a mass of matter from the moon, and transferring it to the earth, in the form of a flaming meteor, or burning stone; at the same time we are utterly ignorant of any other process in nature by which the same phenomenon can be produced. Having thus discovered a way in which it is possible to produce those appearances, we shall now endeavour to shew, from all the concomitant circumstances, that these accord exceedingly well with the natural effects of the supposed cause, and thence give it a very high degree of *probability*.

This important desideratum will perhaps be best attained, by examining the consequences of a substance supposed to be projected by a volcano from the moon, into the sphere of the earth's superior attraction; and then comparing those with the known and visible phænomena of the blazing meteors, or burning stones, that

fall through the air on the earth. And if in this comparison a striking coincidence or resemblance shall always or mostly be found, it will be difficult for the human mind to resist the persuasion, that the assumed cause involves a degree of probability but little short of certainty itself. Now the chief phænomena attending these blazing meteors, or burning stones, are these: 1st. That they appear or blaze out suddenly. 2. That they move with a surprising rapid motion, nearly horizontal, but a little inclined downwards. 3. That they move in several different directions, with respect to the points of the compass. 4. That in their flight they yield a loud whizzing sound. 5. That they commonly burst with a violent explosion and report. 6. That they fall on the earth with great force, in a sloping direction. 7. That they are very hot at first; remain hot a considerable time; and exhibit visible tokens of fusion on their surface. 8. That the fallen stony masses have all the same external appearance and contexture, as well as internally the same nature and composition. 9. That they are totally different from all our terrestial bodies, both natural and artificial.

Now these phænomena will naturally compare with the circumstances of a substance projected by a lunar volcano, and in the order in which they are here enumerated. And first with respect to the leading circumstance, that of a sudden blazing meteoric appearance, which is not that of a small bright spark, first seen at an immense distance, and then gradually increasing with the diminution of its distance. And this circumstance appears very naturally to result from the assumed cause. For, the body being projected from a lunar volcano, may well be supposed in an ignited state, like inflamed matter thrown up by our terrestial volcanoes; which, passing through the comparatively vacuum, in the space between the moon and the earth's sensible atmosphere, it will probably enter the superior parts of this atmosphere with but little diminution of its original heat; from which circumstance, united with that of its violent motion, this being ten or twelve times that of a cannon ball, and through a part of the atmosphere probably consisting chiefly of the inflammable gas, rising from the earth to the top of the atmosphere, the body may well be supposed to become suddenly inflamed, as the natural effect of these circumstances;

indeed it would be surprising if it did not. From whence it appears, that the sudden inflammation of the body, on entering the earth's atmosphere, is exactly what might be expected to happen.

2. Secondly, to trace the body through the earth's atmosphere; we are to observe, that it enters the top of it with the great velocity acquired by descending from the point of equal attraction, which is such as would carry the body to the earth's surface, in a very few additional seconds of time, if it met with no obstruction. But as it enters deeper in the atmosphere, it meets with still more and more resistance, from the increasing density of the atmosphere; by which the great velocity of six miles per second must soon be greatly reduced to one that will be uniform, and only a small part of its former great velocity. This remaining part of its motion will be various in different bodies, being more or less as the body is larger or smaller, and as it is more or less specifically heavy: but for a particular instance, if the body were a globe of twelve inches diameter, and of the same gravity as the atmospheric stones, the motion would decrease so as to be little more than a quarter of a mile per second of perpendicular descent. Now while the body is thus descending, the earth itself is affected by a two-fold motion, both the diurnal and the annual one, with both of which the descent of the body is to be compounded. The earth's motion of rotation, at the equator, is about seventeen miles in a minute, or two-sevenths of a mile in a second; but in the middle latitudes of Europe little more than the half of that, or little above half a quarter of a mile in a second: and if we compound this motion with that of the descending body, as in mechanics, this may cause the body to appear to descend obliquely, though but a little, the motion being nearer the perpendicular than the horizontal direction. But the other motion of the earth, or that in its annual course, is about twenty miles in a second, which is eighty times greater than the perpendicular descent in the instance above-mentioned: so that, if this motion be compounded with the descending one of the body, it must necessarily give it the appearance of a very rapid motion, in a direction nearly parallel to the horizon, but a little declining downwards. A circumstance which exactly agrees with the usual appearances of these meteoric bodies, as stated in the second article of the enumerated phænomena.

3. Again, with regard to the apparent direction of the body, this will evidently be various, being that compounded of the body's descent, and the direction of the earth's annual motion at the time of the fall, which is itself various in the different seasons of the year, according to the direction of the several points of the ecliptic to the earth's meridian or axis. Usually, however, from the great excess of the earth's motion, above that of the falling body, the direction of this must appear to be nearly opposite to that of the former. And in fact this exactly agrees with a remark made by Dr. Halley, in his account of the meteors in his paper above given, where he says that the direction of the meteor's motion was exactly opposite to that of the earth in her orbit. And if this shall generally be found to be the case, it will prove a powerful confirmation of this theory of the lunar substances. Unfortunately, however, the observations on this point are very few, and mostly inaccurate: the angle or direction of the fallen stones has not been recorded; and that of the flying meteor commonly mistaken, all the various observers giving it a different course, some even directly the reverse of others. In future, it will be very advisable that the observers of fallen stones, observe and record the direction or bearing of the perforation, made by the body in the earth, which will give us perhaps the course of the path nearer than any other observation.

4. In the flight of these meteoric stones, it is commonly observed that they yield a loud whizzing sound. Indeed it would be surprising if they did not. For if the like sound be given by the smooth and regularly-formed cannon-ball, and heard at a considerable distance, how exceedingly great must be that of a body so much larger, which is of an irregular form and surface too, and striking the air with 50 or 100 times the velocity.

5. That they commonly burst and fly in pieces in their rapid flight, is a circumstance exceedingly like to happen, both from the violent state of fusion on their surface, and from the extreme rapidity of their motion through the air. If a grinding-stone, from its quick rotation, be sometimes burst, and fly in pieces; and if the same thing happen to cannon-balls, when made of stone, and discharged with considerable velocity, merely by the friction and resistance of the air; how much more is the same to be expected to happen to the atmospheric stones, moving with more

than fifty times the velocity, and when their surface may well be supposed to be partly loosened or dissolved by the extremity of the heat there.

6. That the stones strike the ground with a great force, and penetrate to a considerable depth, as is usually observed, is a circumstance only to be expected, from the extreme rapidity of their motion, and their great weight, when we consider that a cannon-ball, or a mortar-shell, will often bury itself many inches, or even some feet, in the earth.

7. That these stones, when soon sought after and found, are hot, and exhibit the marks of recent fusion, are also the natural consequences of the extreme degree of inflammation in which their surface had been put during their flight through the air.

8. That these stony masses have all the same external appearance and contexture, as well as internally the same nature and composition, are circumstances that strongly point out an identity of origin, whatever may be the cause to which they owe so generally uniform a conformation. And when it is considered, 9thly, that in those respects they differ totally from all terrestrial compositions hitherto known or discovered; they lead the mind strongly to ascribe them to some other origin than the earth we inhabit; and none so likely as coming from our neighbouring planet.

Upon the whole then it appears highly probable, that the flaming meteors, and the burning stones that fall on the earth, are one and the same thing. It also appears impossible, or in the extremest degree improbable, to ascribe these, either to a formation in the superior parts of the atmosphere, or to the irruptions of terrestrial volcanoes, or to the generation by lightning striking the earth. But, on the other hand, that it is possible for such masses to be projected from the moon so as to reach the earth: and that all the phænomena of these meteors, or falling stones, have a surprising conformity with the circumstances of masses that may be expelled from the moon by natural causes, unite in forming a body of strong evidence, that this is in all probability and actually the case.

[*Phil. Trans. Abr.* Vol. VI, p. 100.

SECTION X.

Falling or Shooting Stars.

We have already observed, that there is much doubt as to the origin of this elegant meteor, common as it is to all countries and seasons. The learned writer of the article in the preceding section seems to ascribe them to the same source as the largest and most concrete meteors of the heavens, and consequently to refer them to a lunar source. And, generally speaking, whatever has been the hypothesis entertained concerning the one class, it has been equally applied to explain the other.

"I am unwilling to assert," says Mr. Cavallo, "though I have no particular reason to deny, that the large meteors, and those which are commonly called shooting stars, have a common origin, or are of the same nature, and differ only in size; our utter ignorance of their nature, and the want of accurate observations, do not enable us to form any other distinction. It appears then, that the number of meteors is immense; for the shooting stars, or the meteors of the smallest size, are to be seen in plenty every clear night. Some of them are so small as to be accidentally seen only through telescopes; others are visible to the naked eye, that happens to be directed to that part of the sky; whilst others, by casting more or less light, excite attention and are remarked. The apparent size of these meteors is various; but their apparent motions, when they happen to direct their course nearly at right angles to the spectator, seem not to differ much; whence we may conclude, that they are nearly at equal distances from the earth; and of course they must actually differ in size. This point, however, is much in want of confirmation; and it might be wished, that three or four observers, in a pleasant autumnal evening, were situated at certain distances (for instance ten or twenty miles) from each other, and would endeavour to mark the altitudes of all the shooting stars they saw, together with the time of their appearance. The altitude may be easily ascertained by observing the stars over or near which the meteor passes, and by referring it to a common celestial globe, rectified for the latitude of the place and time of the apparition *."

* Elem. of Philos. vol. iv. p. 365.

Such observations have occasionally been made, and such altitudes remarked with all desirable care and circumspection: and especially by M. M. Benzenberg and Brandes.

The meteors in this case were observed from a base of 46,200 feet F. or 2·1 German geographical miles, fifteen of which make a degree: their height was from four to thirty of those miles; the mean height about eleven, or near fifty English miles. The velocity of two of them was from four to six miles, or about twenty-two English miles in a second. One was brighter than Jupiter, and was 450 miles distant.

In a second paper Dr. Benzenberg gives two instances in detail. September 15. A shooting star of the fifth magnitude. Elevation of the beginning 7·7 geographical miles, of the end 8·2. Length of the path 1·5 miles. Longitude of the place of disappearance 28° 3′; latitude 53° 22′. Observed by Brandes, in Ekwarden, and Benzenberg, in Ham, near Hamburg: length of the base fourteen miles. October 3. Another of the fourth magnitude observed by the same persons. The termination 7·1 geographical miles above the earth. Longitude 27° 7′; latitude 53° 5′. These observations shew, says Dr. Benzenberg, that a long base will furnish as accurate a comparison as a shorter one; that even meteors of the fourth and fifth magnitude may be seen at places distant above fourteen geographical miles from each other; and they confirm the former observations made at Gottingen with a base of but one or two miles.

We will only further observe, as in truth we have partly hinted at before, that Dr. Benzenberg did not believe these small meteors to be of the same nature as the larger. His opinion concerning fiery balls was, that they were revolving bodies distinct from the earth: but he conceived the train of shooting stars to be too numerous for such independent revolving bodies; and with Dr. Chladni objected, that, in such case, they would not appear to ascend, as they are often found to do, as well as to descend. There are, at the same time, various difficulties in the way of regarding them as mere electric scintillæ.

[EDITOR.

* See Gilbert vi. 224, x. 242.

CHAP. XLVII.

ON LUMINOUS AND BURNING EXHALATIONS UNDER THE NAMES OF IGNIS FATUI; WILL-O'-THE-WHISPS; JACK-O'-LANTHORNS; MARINERS' LIGHTS; AND ST. HELMO'S FIRES.

SECTION I.

General Remarks.

THERE is a class of luminous, and not unfrequently inflammable meteors, which yet remains to be described and explained; the cause of which has often been confounded with that of the preceding class; but which in reality is as totally distinct as the phænomena are themselves. These meteors, instead of being composed of exotic materials, are real exhalations from the earth; as gas, vapour, or some other attenuate substance, combined with the matter of light or heat, or both together; which has been eliminated from vegetable, animal, or mineral materials. Instead of being dense or solid they are uniformly rare and subtile; and instead of originating in the loftiest regions of the atmosphere, or beyond its range, are generated for the most part in low marshy plains or valleys. To the fearful and superstitious they are a source of as much terror as the nobler and sublimer meteors we have just contemplated; and it is probable that they have occasionally been the source of real and extensive damage when in a state of actual combustion; and that they have still more frequently seduced a timid and benighted traveller into dangerous bogs, and quagmires. By the learned they are usually denominated *Ignis Fatui*, or *Mock-fires*; and by the vulgar, *Will-o'-the-Whisps, Jack-o'-Lanthorns*; and at sea, or on the coast, *Mariners' Lights*, or *St. Helmo's Fires.*

The true cause of these singular appearances has not often been

Engraved by T.W. Cook, from a Drawing by Pether

For the Gallery of Nature & Art

AN IGNIS FATUUS, OR WILL-O'-THE-WHISP,

As seen in Lincolnshire & taken upon the spot in 1811.

London, Published by E.V. Rose. 46 Holborn Hill, May 1 1820.

very clearly explained, though not difficult to be either given or comprehended.

By far the greatest part of the light we possess is derived from the sun: but there are also numerous kinds of bodies that possess it in a latent or dormant state, and readily give it forth upon being properly excited, or under a proper elevation of temperature; and others that give it forth spontaneously, in the common temperament of the atmosphere. Of the former division are oils, bitumens, vinous spirits, carbon, phosphorus, and hydrogen gas. Of the latter various vegetable and animal substances, on the commencement of putrefaction, which consists in a slow decomposition not wholly unlike combustion; touch-wood, which is wood in a peculiar state of decay; various species of boletus or agaric, and especially that which is denominated spunk; and a multiplicity of worms and insects in a state of perfect health, as pyrosmas, phloades, fire-balls, glow-worms, and elaters*.

It was at one period, as we shall find in the ensuing section, a very general opinion among the learned, that the luminous appearances we refer to, were in every instance produced by phosphorescent insects and worms; but the situations and periods of the year in which they are perhaps most frequently met with, together with a variety of other circumstances, strongly militate against such an idea; and sufficiently prove, that the source of *many* of these meteors is to be sought for in the light exhaled by the decomposition of animal or vegetable materials, magnified, and deepened in hue by the haze or vapoury atmosphere of the moist and swampy low lands in which they are chiefly beheld; and which, in consequence of their moisture and swampiness, are particularly favourable to the process of decomposition.

We may thus account for many of them, and particularly for those that evince no sensible heat during their illumination; for the light exhaled or thrown off from the substances we now allude to, possesses no sensible heat whatever.

It not unfrequently happens, however, that a greater or less degree of heat, a proof of actual though slow combustion, has been evinced during the existence of these phænomena; as also that they have extended more widely than any local decomposition

* See for a fuller account of these curious facts, Books II. and III. of the present work.

would induce us to expect, and have even appeared to change their situation, and to dance about from place to place.

To explain meteors of this kind it is only necessary to observe, that the earth is perpetually exhaling a variety of inflammable gases and other materials, as hydrogen gas or inflammable air, phosphorus, carbonic acid gas, and occasionally sulphureous vapour, sometimes separately, and sometimes in a state of union: and that the most active of these, are particularly evaporating in the low stagnant marsh grounds where these phænomena chiefly make their appearance; and may at any time be collected with the greatest ease, by placing over the surface of the soil an inverted wine-glass or tumbler. Now although these gases will not inflame spontaneously, in the ordinary temperature of the atmosphere, they readily inflame from a great variety of natural causes to which they are perpetually exposed; and hence, in effect, those numerous fire-damps in coal-mines, and other caverns, of which we have given a few tremendous examples in a former part of this work. Electricity may be a common cause of such inflammation; the heat generated during the decomposition of the animal or vegetable materials that may be locally decomposing, may be far more than sufficient for this purpose; for we know it to be sufficient to set hay-stacks on fire, when the grass has been put together in a state sufficiently damp to favour such decomposition. And it is not improbable, that some of these materials may catch the illumination, as from a candle, from a body in the immediate vicinity that is the act of spontaneous illumination.

Now the ball or general mass of inflammable vapour being once lighted or inflamed, from whatever cause, will continue to burn as long as its inflammable principle continues without being destroyed; and its combustible power may be more or less in proportion to its purity or state of concentration; whence in some instances it may pour forth light with little or no sensible heat; in others, the heat combined with it may be sufficient to produce slow combustion like that of a dung-hill; and in others palpable and rapid flame. From the levity of the illumined or burning vapour, moreover, it must necessarily change its place in various instances according to the current of air which it either finds, or by burning makes for itself: and hence it must appear to move in various directions, upwards and downwards, to the right and to the left, from object to object,

in a constant dance before the spectator, according to the motion, because that operates upon it: while its colours and dimensions must vary according to the varying density of the fog, or haze, through which, in different places or situations, it is seen, or according to its actually increasing or diminishing and decaying bulk: hence, in our opinion, the usual origin of this class of singular meteors.

We hazard the opinion, however, with much diffidence, and shall leave it to our readers to adopt, or reject, as its merit may respectively strike them: and shall only further observe, before we proceed to offer a few examples of them, that while in all countries they are for the most part to be met in wet swampy lowlands, and stagnant marshes or morasses; they more usually occur, and with greater lustre, in hot climates, upon the approach of winter, when the sky, after wearing a fiery brightness, begins to be overcast, and the whole horizon to be wrapped as in a muddy cloud. Mists and vapours, says an intelligent writer, at this time continue to rise with peculiar density throughout all the regions under the line: the air which so lately before was clear and elastic, now becomes humid, obscure, and stifling: the fogs become so thick, that the light of the sun seems in a manner excluded; nor would its presence be known, but for the intense and suffocating heat of its beams, which dart through the gloom, and, instead of dissipating, only serve to increase the mist. After this preparation, there follows an almost continual succession of thunder, rain, and tempests. During this dreadful season, the streets of cities flow like rivers, and the whole country wears the appearance of an ocean. The inhabitants often make use of this opportunity to lay in a stock of fresh water for the rest of the year; as the same cause which pours down the deluge at one season, denies the kindly shower at another. The thunder which attends the fall of these rains, is much more terrible than that we are generally acquainted with. Among ourselves, the flash is seen at some distance, and the noise shortly after ensues; our thunder generally rolls on one quarter of the sky, and one stroke pursues another. But here the whole sky appears abruptly illuminated with unremitted flashes of lightning; every part of the air seems productive of its own thunders; and every cloud produces its own shock. The strokes come so thick, that the inhabitants can scarcely

mark the intervals; and all is one unremitted roar of elementary confusion. It should seem, however, that the lightning of those countries is not so fatal, or so dangerous, in proportion to its energy, as that with us; since in this case, the torrid zone would be uninhabitable.

When these terrors have ceased, with which, however, the natives are familiar, meteors of another kind begin to make their appearance. The intense beams of the sun, darting upon stagnant waters, that generally cover the surface of the country, raise vapours of various kinds. Floating bodies of fire, which assume different names, rather from their accidental forms than from any real difference between them, are seen without surprise. The draco volans, or flying dragon; will-o'-the-wisp; the ignis fatuus, or wandering fires of St. Helmo, or the mariners' light, are every where frequent; and of these we have numberless descriptions.

EDITOR.

SECTION II.

Of the Ignis Fatuus, as observed in England.

By Sir Thomas Dereham, Bart. F. R. S. the Rev. William Derham, F. R. S. and others.

It being the opinion of divers skilful naturalists, particularly Mr. Fr. Willoughby, and Mr. Ray, that ignis fatui are only the shining of a great number of the male glow-worms in England, or of the pyraustæ in Italy, flying together, Mr. D. consulted his friend, Sir Thomas Dereham, about the phenomenon, being informed that those ignis fatui are common in all the Italian parts. But of the pyraustæ, or fire-flies, he says, he never observed any such effects, though there is an immense number of them in June and July. He also says, that these pyraustæ are called Lucciole, *i. e.* small lights, and that they are not the farfalls, as Mr. Ray thought, which are butterflies.

But Mr. D. has reason to think, that insects are not concerned in the ignis fatui, from the following observations; the first made by himself, and the others received from Italy, by the favour of Sir Thomas Dereham.

His own observation he made at a place in a valley between

rocky hills, which he suspected might contain minerals, in some boggy ground near the bottom of those hills. Where, seeing one in a calm, dark night, with gentle approaches, he got up within two or three yards of it, and viewed it with all possible care. He found it frisking about a dead thistle growing in the field, till a small motion of the air made it skip to another place, and thence to another, and another.

It is about fifty-five years since he saw this phenomenon, but he had as fresh and perfect an idea of it, as if it was but a few days. And as he took it then, so he is of the same opinion now, that it was a fired vapour.

The male glow-worms Mr. D. knows emit their shining light, as the fly; by which means they discover and woo the females; but he never observed them to fly together in so great numbers, as to make a light equal to an ignis fatuus. And he was so near, that had it been the shining of glow-worms, he must have seen it in little distinct spots of light; but it was one continuous body of light.

As to the communication from Italy, it is observed that these lights are pretty common in all the territory of Bologna. In the plains they are very frequently observed; the country people call them cularsi, perhaps from some fancied similitude to those birds; and because they consider them as birds, the belly and other parts of which are resplendent like our shining flies. They are most frequent in watery and morassy ground, and there are some such places, where one may be almost sure of seeing them every night, if it be dark; some of them giving as much light as a lighted torch, and some no larger than the flame of a common candle. All of them have the same property in resembling, both in colour and light, a flame strong enough to reflect a lustre on neighbouring objects all around. They are continually in motion, but this motion is various and uncertain. Sometimes they rise up, at others they sink. Sometimes they disappear of a sudden, and appear again in an instant in some other place. Commonly they keep hovering about six feet from the ground. As they differ in size, so also in figure, spreading sometimes pretty wide, and then again contracting themselves. Sometimes breaking to all appearance into two, soon after meeting again into one body; sometimes floating like waves, and letting drop some parts like sparks out of a fire. And

in the very middle of the winter, when the weather is very cold, and the ground covered with snow, they are observed more frequently than in the hottest summer. Nor does either rain or snow in any wise prevent or hinder their appearance; on the contrary, they are more frequently observed, and cast a stronger light, in rainy and wet weather. But since they do not receive any damage from wet weather; and since, on the other hand, it has never been observed, that any thing was set on fire by them, though they must needs in their moving to and fro, meet with a good many combustible substances, it may from thence be inferred, that they have some resemblance to that sort of phosphorus that shines in the dark, without burning any thing. As to the appearance of this phenomenon in mountainous parts, they differ in nothing else but in size; these latter being never observed any larger than the flame of an ordinary candle. In general, these lights are great friends to brooks and rivers, being frequently observed along their banks; perhaps because the air carries them thither more easily than any where else. In all other particulars, as in their motion, the manner of their appearance, their disappearing sometimes very suddenly, their light, the height they rise to, and their not being affected either by rainy or cold weather, they are the very same with the cularsi above described, or the large will-o'-the-wisp, as observed in the plains.

A young gentleman, a very accurate and skilful observer of natural appearances, travelling sometime in March last, between eight and nine in the evening, in a mountainous road, about ten miles south of Bologna, as he approached a certain river, called Rioverde, he perceived a light, which shone very strongly on some stones that lay on the banks. It seemed to be about two feet above the stones, and not far from the water of the river: in figure and size it had the appearance of a parallelopiped, somewhat above a Bolognese foot in length, and about half a foot high, its longest side lying parallel to the horizon: its light was very strong, insomuch that he could very plainly distinguish by it part of a neighbouring hedge, and the water in the river. The gentleman's curiosity tempted him to examine it a little nearer; in order to which, he advanced gently towards the place, but was surprised to find, that insensibly it changed from a bright red to a yellowish, and then to a pale colour, in proportion as he drew nearer; and that

when he came to the place itself, it was quite vanished. On this he stepped back, and not only saw it again, but found that the farther he went from it, the stronger and brighter it grew; nor could he, on narrowly viewing the place where this fiery appearance was, perceive the least blackness, or smell, or any mark of an actual fire. The same observation was confirmed by another gentleman, who frequently travels that way, and who asserted, that he had seen the very same light five or six different times, in spring and autumn, and that he had always observed it in the very same shape and the same place, which seems very difficult to be accounted for. He said further, that once he took particular notice of its coming out of a neighbouring place, and then settling itself into the figure above-described.

[*Phil. Trans. Abr.* 1729.

SECTION III.

Luminous and Inflammable Exhalation on the Snows of the Appennines.

We have ventured in the first section of this chapter to ascribe the greater number of luminous exhalations that float over the surface of the earth to the extrication and inflammation of hydrogen gas, similar to that which is so frequently elicited in coal mines, under the name of fire-damp. In the midst of the snows on the summit of the Appennines, was traced in the middle of last century, a luminous and burning exhalation, which evidently proceeded from this cause. It is clearly and accurately described by Robert More, Esq. in a letter published in the Philosophical Transactions, vol. xlvii.; in which, among other facts of natural history, he observes that the fire among the snows on the summit of the Appennines is of the same sort with that about a little well at Brosely*, in Shropshire; of which the Society has had an account; the same as of the foul air sent them from Sir James Lowther's† coal pits; and the like made by a gentleman with filings of iron and oil of vitriol. The flame, when he saw it, was extremely bright, covered a surface of about three yards by two, and rose about four fee

* See Philos. Trans. No. 482.—Orig.

† No. 482, No. 442.—Orig.

high. After great rains and snows, they said, the whole bare patch, of about nine yards diameter, flames. The gravel, out of which it rises, at a very little depth, is quite cold. There are three of these fires in that neighbourhood; and there was one they call extinct. He went to the place to light it up again, and left it flaming. The middle of the last place is a little hollowed, and had in it a puddle of water: there were strong ebullitions of air through the water; but the air would not take fire; yet what rose through the wet and cold gravel flamed brightly. Near either of these flames, removing the surface of the gravel, that below would take fire from lighted matches.

[*Phil. Trans.* 1750.

SECTION IV.

1. *Fiery Exhalations or Damp, that set on Fire various Hay-Ricks in Pembrokeshire.*

In a Letter from Mr. Edward Floyd to Dr. Leister, F.R.S. dated Jan. 20, 1693-4.

I am wholly intent at present on giving you the best account I can of a most dismal and prodigious accident at Hartech in this county (Pembrokeshire), from the 24th to the 30th of December, 1693. It is of the unaccountable firing of sixteen ricks of hay, and two barns, one full of corn, the other of hay. I call it unaccountable, because it is evident they were not burnt by common fire, but by a kindled exhalation, which was often seen to come from the sea, and lasted at least a fortnight or three weeks, and annoyed the country, both by poisoning the grass and firing the hay, for the space of a mile. It was a weak blue flame, easily extinguished, and did not in the least burn any of the men who interposed their endeavours to save the hay, though they ventured not only close to it, but sometimes into it. All the damage sustained happened constantly in the night. There are three small tenements in the same neighbourhood, where the grass is so infected, that it absolutely kills all manner of cattle that feed on it. The grass has been infectious these three years, but not thoroughly fatal till this last.

2. *Continuation of the above account, from the same to the same, dated August* 23, 1694.

An intelligent person, who lives near Harlech in Merioneth-shire, assured me the fire still continues there; that it is observed to come from a place called Morva-bychan in Caernarvonshire, about eight or nine miles off, over part of the sea. That cattle of all sorts, as sheep, goats, hogs, cows, and horses, still die apace; and that for certain, any great noise, as winding horns, drums, &c. repels it from any house, or barn, or stacks of hay; on account of which remedy, they have had few or no loses in that kind since Christmas. That it happened during this summer, at least one night in a week, and that commonly either Saturday or Sunday; but that now of late it appears something oftener. The place whence it proceeds is both sandy and marshy.

[*Phil. Trans.* 1693-4.

It is not impossible that the winding of horns, drums, and other noises here referred to may have been serviceable in destroying the flame; if, as there can be little doubt, the inflammable material were hydrogen gas; for whatever would tend to change and ventilate the gas, as loud sounds must necessarily do, would speedily render it weaker, or in other words, more freely combined with the uninflammable air of the atmosphere.

[Editor.

CHAP. XLVIII*.

On atmospheric deceptions.—Fata Morgana, mirages, glamer or looming; halos; multiplied rainbows; parhelions, and paraselenites, or mock-suns, and mock-moons; glories; refraction of Iceland crystal.

SECTION I.

Explanation of the principle of Atmospheric Deceptions.

All these curious and interesting phænomena proceed from one common cause, irregularity in the tenuity of the atmospheric fluid. To enter, however, very fully into their origin and distinctions, would lead us farther into the laws of optics than the nature of the present work would justify. One of the clearest and most concise explanations that has occurred to us, and at the same time most adapted to popular comprehension, is contained in a note to Mr. Good's Translation of Lucretius, book iv. v. 144, in which the poet enters upon a description of the *mirage* (or *glamer* as it is called in the Highlands) a distorted and fantastic representation of the scenery before us—a description which we regret that we have not space to copy. The note is as follows:

These monstrous appearances in the atmosphere are not equally common to all countries, but depend in a great measure upon local causes and combinations. According to Pliny, the regions of Scythia, within Imaus; and according to Pomponius Mela, those of Mauritania, behind mount Atlas, are peculiarly subject to them; and they are generally regarded by the barbarous inhabitants of such countries as spectres, or aërial demons. Of such grotesque

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* It might perhaps be expected, before we thus enter upon a new subject, that we should touch upon the phenomenon of Fairy Rings, or Circles; which have from a very high antiquity been generally ascribed to the effect of lightning, or fiery meteors of some kind or other. More accurate attention, however, has proved them to be the production of a fungus, the agaricus orcades, and hence to fall within the range of the curiosities of *Botany*.

[Editor.

phænomena, Diodorus Siculus makes particular mention in the fiftieth section of his third book, and points out the regions of Africa situate between the Syrtes and Cyrene, as the theatre of their most extraordinary appearance: περι γαρ τινας καιρους, says he, και μαλιστα κατα τας νηνεμιας, συστασεις ορωνται κατα τον αερα, παντοιων ΖΩΩΝ ιδεας εμφαινουσαι· τουτων δ', αι μεν ηρεμουσιν, αι δε κινησιν λαμβανουσι· και ποτε μεν υποφευγουσι, ποτε δε διωκουσι. "Even in the serenest weather, there are sometimes seen in the air certain condensed exhalations, that represent the figures of all kinds of animals; occasionally, they seem to be motionless, and in perfect quietude; and occasionally to be flying; while immediately afterwards, they themselves appear to be the pursuers, and to make other objects fly before them." This phenomenon is, in reality, seldom observed, except in serene weather; and it should seem, upon every theory yet offered to account for it, from the ingenious explanation of our own poet to that of M. Monge, in the Memoirs relative to Egypt, that such an atmosphere is nearly or altogether necessary to its existence. The illusion has been noticed as frequently by modern as by ancient observers; and M. Crantz, in his History of Greenland, Vol. I. 49, has given a picture of it, not essentially differing from the above just quoted from Diodorus Siculus. It is not confined to any particular part of the globe, but generally makes its appearance on the coast; the atmosphere, as I have already observed, being commonly clear and tranquil, and the phenomenon usually succeeded by a fall of rain. Our own sailors, from its more general appearance, call it a fog-bank; by many writers, it is denominated *fata Morgana*, and by the French, *mirage*.

For this atmospheric delusion, various causes have been assigned; and especially by Kircher, Scholt, and Gaspard Monge, who accompanied Buonaparte in his Egyptian expedition, as one of the French Sçavans, and was a member of the Institute at Cairo: yet no explanation I have hitherto met with, has been given in satisfactory, or at least in popular language.

To illustrate it as clearly as may be, it is necessary, first of all, to call the reader's attention to the variable state of the atmosphere; which is commonly of an homogeneous, or equable tenuity, and consequently suffers the rays of the sun to penetrate it without any obstruction or change; but at times it is irregular, and composed of

parts or bodies of a denser medium than its general texture and constitution: in which case the fluent ray, if it do not enter the denser medium in a direct or perpendicular line, will be either reflected, or refracted, or both; and the object surveyed through it assumes a new, and not unfrequently a grotesque appearance.

There are various causes that produce such irregularities in the tenor of the atmospheric fluid; of which, perhaps, the most common is the descent of rain, whose globules, when opposed to the sun or the moon, at their rising or setting, in a clear sky, are well known to exhibit the phenemenon of the rainbow: a phenomenon which depends upon the very principle now adverted to; and proceeds, indeed, from a double reflection and refraction; or, in other words, from the globule which produces the arch being converted into a double mirror, and a double prism. In the formation of this beautiful meteor, it is necessary to observe, that the ray which issues from the centre of the sun, and does not immediately, or perpendicularly, pass through the centre of the opposed globule of rain, must, upon the common principles of dioptrics, in consequence of its entering a transparent body of a different medium from the atmosphere itself, in a certain degree, be bent, deflected, or refracted from the right line in which it was proceeding; and hence, instead of passing out at the posterior part of the globule, immediately opposite to that at which it entered, it will be driven towards another limb, or marginal portion of the globule, and form an angular line co-equal to the obliquity with which it deviates from a right line on its entrance into the globule; just as a stake, or the oar of a boat, plunged obliquely into a river, appears to be broken, or deflected, from the point at which it enters the water. At this point, the refracted ray, instead of passing out of the globule, suffers another deflection, but from a very different cause; for the ray of light having been thrown across a certain portion of the posterior chamber of the globule of rain, without permeating it, all behind its passage becomes necessarily a dark shade, while the globule itself forms an anterior and polished surface to it; whence a regular mirror is produced, and the ray is now reflected or thrown back from it, in the same manner as an incident ray of light, or image, is reflected or thrown back from a looking-glass, or a deep and clear stream of water; both of which, like the globule thus situated, consist of nothing more than a dark shadow with a

polished surface: the obliquity of its path, in the present instance, being precisely similar to that which it has previously suffered from refraction; the angular line of reflection being always co-equal with the angular line of incidence. It is hence obvious, that the ray, or fascicle of parallel rays, which entered obliquely below the centre of the globule, opposed to the centre of the sun, must be reflected obliquely above it; and as the same process necessarily takes place, but in an inversed order, with the antagonist ray, or fascicle of parallel rays that entered with the same degree of obliquity above it, it is also obvious that, from this double refracting and reflecting power of an individual globule of rain, situated as above described, an angle of light must be formed, from their antagonism alone, exhibiting the different colours of which they consist in a definitive order, according to the degree of their refrangibility: that the spread, or hypotheneuse of the angle must depend upon the diameter of the globule which produces it; and that its point being softened or obtunded to the eye by the distance through which it is beheld, agreeably to an observation of our poet in v. 375 of Good's Lucretius, the angle must be converted into an arch. And hence, a beautiful and variegated rainbow must necessarily result from a few rays of light acted upon by a single globule of rain, situated as above, from the fact alone of its possessing the power of a binary mirror or sprism.

But a globule of rain is not the only substance in the atmosphere capable, at times, of producing the same effect; nor, since we are told that the mirage usually occurs when the sky is peculiarly tranquil and serene, could it be the cause of this last equally curious phenomenon. Our time, however, has not been lost in thus hastily investigating the theory of the iris; for the same principles will apply to the meteor before us. We are informed, not only that the mirage is chiefly to be noticed when the sky is clear and unclouded, but in the morning, and principally upon the coasts or banks of a large river. The mirage beheld by M. Crantz was on the shore of the Kookoernan islands, near the Cape of Good Hope; it has often been traced at the back of the Isle of Wight; but the quarter, in which, perhaps, it most frequently makes its appearance, is the Faro of Messina, in Italy. In all these places, when the weather is perfectly calm, and, consequently, the sea almost without motion, the atmosphere, more especially in a dry and hot sea-

son, imbibes a considerable portion of the water upon which its lower stratum presses; and hence, in the night-time, becomes condensed and hazy. As the morning rises, however, and the sunbeams resume their vigour, the atmosphere once more rarefies, and re-acquires its transparency. If it rarefy equably, and homogeneously, every object beheld through it must necessarily be exhibited in its real proportion and figure: but it happens, occasionally, that in some parts of its texture, it seems to be more closely interwoven than in others; and hence in its general expansion, *veins*, or *striæ*, like those often discovered in glass, make their appearance, of different densities and diameters. In this case, every *stria*, like every globule of rain, in consequence of the variation of its density from the common density of the atmosphere, becomes a refracting or a reflecting body; in other words, a prism, or a mirror, or both. If, then, a single globule of rain, properly disposed, be able to produce a phenomenon so marvellous as that of the rainbow, what phænomena may we not expect, what variation, inversion, contortion, and grotesque and monstrous representation of images, beheld through a column of the atmosphere, intersected by so many aërial prisms of different densities, and mirrors of different surfaces, in which the catheti may be innumerable, and for ever varying? We may hence, moreover, readily trace the cause of an occasional duplication of images in the atmosphere, of a parhelion, and paraselene, or double sun, and double moon, from the reflection of these luminaries in an opposite part of the heavens, when they are a little above the horizon; as also of the very curious mirage remarked by M. Monge, in the hot and sandy desert between Alexandria and Cairo; in which, from an inverted image of the cerulean sky intermixed with the ground scenery, the neighbouring villages appeared to be surrounded with the most beautiful sheeting of water, and to exist, like islands, in its liquid expanse, tantalizing the eye by an unfaithful representation of what was earnestly desired.

The mirage has not been suffered to lie neglected by the poets. It is to the aërial phantoms exhibited by this meteor, that Milton alludes in the following verses:

> As when, to warn proud cities, war appears
> Waged in the troubled sky, and armies rush

To battle in the clouds; before each van
Prick forth the airy knights, and couch their spears,
Till thickest legions close; with feats of arms
From either side of heaven the welkin burns.
[*Good's Lucretius*, vol. ii. p. 25.

SECTION II.

Fata Morgana, or Optical Appearances of Figures in the Sea and Air, in the Faro of Messina.

As when a shepherd of the Hebrid Isles
Placed far amid the melancholy main,
(Whether it be lone fancy him beguiles,
Or that aërial beings sometimes deign
To stand, embodied, to our senses plain)
Sees on the naked hill, or valley low,
The whilst in ocean Phœbus dips his wain,
A vast assembly moving to and fro;
Then all at once in air dissolves the wond'rous shew.

THOMSON.

Various philosophical writers and travellers, and among them our English travellers Brydone and Swinburne, make mention of a very striking phenomenon which occasionally appears in the Straits of Messina, and is known by the name of Fata Morgana, or, as some render it, the castles of the Fairy Morgana. The accounts differ from each other, as well with respect to the appearances, as the concomitant circumstances which are supposed to be necessary for producing them. How far the effects themselves may be subject to variation; or to what extent the imagination of the narrators, who speak of the exhibition as calculated to produce astonishment, may be subject to irregularity, would admit of discussion; but the general certainty of the events is matter of universal notoriety, and admits of no doubt. I have not had the good fortune to meet with any of the authors who treat on this subject expressly from their own knowledge and observation, till lately that the Dissertation of Minasi was lent me by the Right Honourable Sir Joseph Banks, Bart., &c. In this treatise the facts are related with much simplicity and precision, and the philosophical reasoning of the author is kept distinct from the narrative. I have therefore chosen to collect the present account from this author.

His first chapter contains a description of the phenomenon. "When the rising sun shines from that point whence its incident ray forms an angle of about forty-five degrees on the sea of Reggio, and the bright surface of the water in the bay is not disturbed either by the wind or the current, the spectator being placed on an eminence of the city, with his back to the sun and his face to the sea;—on a sudden there appear in the water, as in a catoptric theatre, various multiplied objects; that is to say, numberless series of pilastres, arches, castles well delineated, regular columns, lofty towers, superb palaces, with balconies and windows, extended alleys of trees, delightful plains with herds and flocks, armies of men on foot and horseback, and many other strange images, in their natural colours and proper actions, passing rapidly in succession along the surface of the sea, during the whole of the short period of time while the above-mentioned causes remain.

" But if, in addition to the circumstances before described, the atmosphere be highly impregnated with vapour and dense exhalations, not previously dispersed by the action of the wind or waves, or rarefied by the sun, it then happens that in this vapour, as in a curtain extended along the channel to the height of about thirty palms, and nearly down to the sea, the observer will behold the scene of the same objects not only reflected from the surface of the sea, but likewise in the air, though not so distinct or well-defined as the former objects from the sea.

" Lastly, if the air be slightly hazy and opake, and at the same time dewy and adapted to form the iris, then the above-mentioned objects will appear only at the surface of the sea, as in the first case, but all vividly coloured or fringed with red, green, blue, and other prismatic colours."

The author therefore distinguishes three sorts of Fata Morgana: that is to say, the first at the surface of the sea, which he calls the Marine Morgana; the second in the air, called the Aërial Morgana: and the third only at the surface of the sea, which he calls the Morgana fringed with prismatic colours.

In a note in this chapter P. Minasi enquires into the etymology of Morgana. After various remarks, he thinks the opinion of those who derive this word, which is so foreign to the Roman idiom, from μωϱος tristes and γανοω lætitia afficio, is not far from the truth; considering the great exultation and joy this appearance

produces in all ranks of people, who on its first commencement run hastily to the sea, exclaiming Morgana, Morgana! He remarks that he has himself seen this appearance three times, and that he would rather behold it again than the most superb theatrical exhibition in the world.

In the second chapter the author describes the city of Reggio, and the neighbouring coast of Calabria: by which he shows that all the objects which are exhibited in the Fata Morgana are derived from objects on shore.

In his third chapter, consisting of physical and astronomical observations, he affirms that the sea in the straits of Messina has the appearance of a large inclined speculum; that in the alternate current, or tide, which flows and returns in the straits for six hours each way, and is constantly attended by an opposite current along shore to the medium distance of about a mile and a half, there are many eddies and irregularities at the time of its change of direction: and that the Morgana usually appears at this period. Whence he enters into considerations of the relative situations of the sun and moon, which are necessary to afford high water at the proper time after sun-rise, as before described. It is high water, that is to say, the northern current ceases, at full and change, at nine o'clock. There is probably a small rise and fall, though the annotation to a large chart before me affirms that there is none.

In the fourth chapter and subsequent part of the work, the author collects the opinion and relations of various writers on this subject; namely, Angelucci, Kircher, Scotus, and others; and he afterwards proceeds to account for the effects, by the supposed inclination of the surface of the sea, and its subdivision into different plains by the contrary eddies. The aërial effects are referred to considerations of saline and other effluvia suspended in the air; which I forbear to abridge, because it seems difficult to make any clear or productive statement either from the narrative or the reasoning.

What I seem to collect upon the whole from the several relations, brought into one point, is as follows: 1. That by the situation of the Faro of Messina, the current from the south, at the expiration of which this phenomenon is most likely to appear, is so far impeded by the figure of the land, that a considerable por-

tion of the water returns along shore. 2. That it is probable the same coasts may have a tendency to modify the lower portion of the air in a similar manner, during the southern breeze; or, in other words, that a sort of bason is formed by the land, in which the lower air is more disposed to become motionless and calm than elsewhere. 3. That the Morgana Marina presents inverted images below the real objects, which are multiplied laterally as well as vertically; and that there are repetitions of the same multiplied objects at more considerable vertical intervals. This I gather from the appearance of the dome and other objects in the plate. 4. That the Aërial Morgana is not inverted, but, as I am disposed to conjecture, is more elevated than the original objects. 5. That the fringes of prismatic colours are produced in falling vapours, similar to many appearances which have been described by authors, but not accurately explained by the general principles of refraction through spheres of water. The ship is referred to by the author as an object surrounded by these fringes: whence it appears that the colours apply to the direct rays from objects, as well as to those of the Marine Morgana. 6. Various other objects in the drawing, as well as in the description, afford matter for question and conjecture, but none perhaps which it may be proper to enlarge upon, until the theory be better known. 7. It seems at all events more probable that these appearances are produced by a calm sea, and one or more strata of superincumbent air, differing in refractive, and consequently reflective power; than from any considerable change in the surface of the water, with the laws of which we are much better acquainted than with those of the atmosphere. 8. By attentive reflection upon the facts and reasonings in Mr. Huddart's paper, we may form a theory to account for the erect and inverted images: the polished surface of the sea may perhaps account for the vertical repetition; but for the lateral multiplication we must have recourse to reflecting or refracting planes in the vapour, which appear nearly as difficult to deduce or establish, as those which have been supposed on the water.

Swinburne gives the following account of this singular phenomenon, which we quote as affording a stronger proof of the correctness of the hypothesis advanced in the preceding section. Sometimes, but rarely, it (the Faro) exhibits a very curious phenomenon, vul-

garly called La Fata Morgana*. The philosophical reader will find its causes and operations learnedly accounted for in Kircher, Minasi, and other authors. I shall only give a description of its appearance, from one that was an eye-witness. Father Angelucci is the first that mentions it with any degree of accuracy, in the following terms:

"On the 15th of August, 1643, as I stood at my window, I was surprised with a most wonderful, delectable vision. The sea that washes the Sicilian shore swelled up, and became, for ten miles in length, like a chain of dark mountains; while the waters near our Calabrian coast grew quite smooth, and in an instant appeared as one clear polished mirror, reclining against the aforesaid ridge. On this glass was depicted, in *chiaro scuro*, a string of several thousands of pilasters, all equal in altitude, distance, and degree of light and shade. In a moment they lost half their height, and bent into arcades, like Roman aqueducts. A long cornice was next formed on the top, and above it rose castles innumerable, all perfectly alike. These soon split into towers, which were shortly after lost in colonnades, then windows, and at last ended in pines, cypresses, and other trees, even and similar. This was the Fata Morgana, which, for twenty-six years, I had thought a mere fable."

To produce this pleasing deception, many circumstances must concur, which are not known to exist in any other situation. The spectator must stand with his back to the east, in some elevated place behind the city, that he may command a view of the whole bay; beyond which the mountains of Messina rise like a wall, and darken the back-ground of the picture. The winds must be hushed, the surface quite smoothed, the tide at its height, and the waters pressed up by currents to great elevation in the middle of the channel. All these events coinciding, as soon as the sun surmounts the eastern hills behind Reggio, and rises high enough to form an angle of forty-five degrees on the water before the city, every object existing or moving at Reggio will be repeated a thousand-fold upon this marine looking-glass; which, by its tremulous motion, is, as it were, cut into facets. Each image will pass ra-

* The name is probably derived from an opinion, that the whole spectacle is produced by a fairy, or a magician. The populace are delighted whenever the vision appears, and run about the streets, shouting for joy,—calling every body out to partake of the glorious sight.

pidly off in succession, as the day advances, and the stream carries down the wave on which it appeared.

Thus the parts of this moving picture will vanish in the twinkling of an eye. Sometimes the air is at that time so impregnated with vapours, and undisturbed by winds, as to reflect objects in a kind of aërial screen, rising about thirty feet above the level of the sea. In cloudy heavy weather, they are drawn on the surface of the water, bordered with fine prismatical colours.

[*Nicholson's Journ. 4to. Vol.* ii. *Swinburne.*

SECTION III.

Singular Instance of Atmospherical Refraction, by which the Coast of Picardy, with its more prominent Objects, was brought apparently close to that of Hastings.

By William Latham, Esq. F. R. S. and A. S.

July 26, about five o'clock in the afternoon, while sitting in my dining-room at this place, Hastings, which is situated on the Parade, close to the sea-shore, nearly fronting the south, my attention was excited by a great number of people running down to the sea-side. On inquiring the reason, I was informed that the coast of France was plainly to be distinguished with the naked eye. I immediately went down to the shore, and was surprised to find that, even without the assistance of a telescope, I could very plainly see the cliffs on the opposite coast; which at the nearest part, are between forty and fifty miles distant, and are not to be discerned, from that low situation, by the aid of the best glasses. They appeared to be only a few miles off, and seemed to extend for some leagues along the coast. I pursued my walk along the shore to the eastward, close to the water's edge, conversing with the sailors and fishermen on the subject. At first they could not be persuaded of the reality of the appearance; but they soon became so thoroughly convinced, by the cliffs gradually appearing more elevated, and approaching nearer, as it were, that they pointed out, and named to me, the different places they had been accustomed to visit; such as, the Bay, the Old Head or Man, the Windmill, &c. at Boulogne; St. Vallery, and other places on the coast of Picardy; which they afterwards confirmed, when they viewed them through their telescopes. Their observations were, that the places

appeared as near as if they were sailing, at a small distance, into the harbours.

Having indulged my curiosity on the shore for near an hour, during which the cliffs appeared to be at some times more bright and near, at others more faint and at a greater distance, but never out of sight, I went on the eastern cliff or hill, which is of a very considerable height, when a most beautiful scene presented itself to my view; for I could at once see Dengeness, Dover cliffs, and the French coast, all along from Calais, Boulogne, &c. to St. Vallery; and, as some of the fishermen affirmed, as far to the westward even as Dieppe. By the telescope, the French fishing-boats were plainly to be seen at anchor; and the different colours of the land on the heights, with the buildings, were perfectly discernible. This curious phenomenon continued in the highest splendour till past eight o'clock, though a black cloud totally obscured the face of the sun for some time, when it gradually vanished. I was assured, from every inquiry I could make, that so remarkable an instance of atmospherical refraction had never been witnessed by the oldest inhabitant of Hastings, nor by any of the numerous visitors come to the great annual fair. The day was extremely hot. I had no barometer with me, but suppose the mercury must have been high, as that and the three preceding days were remarkably fine and clear. To the best of my recollection, it was high water at Hastings about two o'clock P. M. Not a breath of wind was stirring the whole of the day; but the small pennons at the mast-heads of the fishing-boats in the harbour were in the morning at all points of the compass. I was, a few days afterwards, at Winchelsea, and at several places along the coast, where I was informed the above phenomenon had been equally visible. When I was on the eastern hill, the cape of land called Dengeness, which extends nearly two miles into the sea, and is about sixteen miles distant from Hastings, in a right line, appeared as if quite close to it; as did the fishing-boats and other vessels, which were sailing between the two places; they were likewise magnified to a great degree *.

[*Phil. Trans.* 1798.

* In this case, as in that of the desert between Alexandria and Cairo, adverted to in section i. the refractive power of the atmosphere was probably produced by a diminution of the density of its lower stratum, in consequence of the increase of heat communicated to it by the rays of the sun

SECTION IV.

On Refractions and double Refractions in the Atmosphere.

We have endeavoured, in the first section, to present the reader with a clear outline of the chief principles upon which the atmospherical deceptions we have thus far noticed are founded. There is, however, another cause which has of late years been brought forward as of the utmost importance in their production; and particularly in the production of that double refraction which is the principal source of multiplied rainbows, parhelions, and paraselinites, or mock-suns and mock-moons, glories, and the singular refracting power of the Iceland crystal. This cause is the tendency of plates or strata of different thickness both to vary the refraction, and to alter the intensity or the order of the colours. In the Philosophical Transactions we meet with two excellent articles upon this subject: one by Mr. Huddart, and the other by Dr. Wollaston, but of too abstruse a character for introduction into the present work. We shall, however, in order to render the subject more

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powerfully reflected from the surface of the earth. In another article in the same volume of the Philosophical Transactions, Professor Vince observes, that he remarked a similar apparent approximation of the French coast to that of Ramsgate, in the summer of 1798. "Of two ships," says he, "which in different parts were equally sunk below the horizon, the inverted image of one would but just begin to appear, while that of the other would represent nearly the whole of the ship. But this I observed in general, that as the ship gradually descended below the horizon, more of the image gradually appeared, and it ascended; and the contrary when the ships were ascending. On the horizon, in different parts, one ship would have a complete inverted image; another would have only a partial image; and a third would have no image at all. The images were in general extremely well defined; and frequently appeared as clear and sharp as the ships themselves, and of the same magnitude. Of the ships on this side of the horizon, no phænomena of this kind appeared. There was no fog on our coast; and the ships in the Downs and the South Foreland exhibited no uncommon appearances. The usual refraction at the same time was uncommonly great; for the tide was high, and at the very edge of the water I could see the cliffs at Calais a very considerable height above the horizon; whereas they are frequently not to be seen in clear weather from the high lands about the place. The French coast also appeared, both ways, to a much greater distance than I ever observed it at any other time, particularly towards the east, on which part also the unusual refraction was the strongest.

easily comprehensible, take leave, prior to our giving a few examples of these singular phænomena, to copy Dr. Young's very neat abridgment of the last paper, and to introduce it with a few valuable observations of his own.

The atmospherical phænomena, says he, of rainbows and halos present us with examples of the spontaneous separation of colours by refraction. The rainbow is universally attributed to the refraction and reflection of the sun's rays, in the minute drops of falling rain or dew; and the halos, usually appearing in frosty atmospheres, are in all probability produced by the refraction of small triangular or hexagonal crystals of snow. It is only necessary, for the formation of a rainbow, that the sun should shine on a dense cloud, or a shower of rain, in a proper situation; or even on a number of minute drops of water, scattered by a brush or by a syringe, so that the light may reach the eye after having undergone a certain angular deviation, by means of various refractions and reflections; and the drops so situated must necessarily be found somewhere in a conical surface, of which the eye is the vertex, and must present the appearance of an arch. The light, which is reflected by the external surface of a sphere, is scattered almost equally in all directions, setting aside the difference arising from the greater efficacy of oblique reflection; but when it first enters the drop, and is there reflected by its posterior surface, its deviation never exceeds a certain angle, which depends on the degree of refrangibility, and is, therefore, different for light of different colours: and the density of the light being the greatest at the angle of greatest deviation, the appearance of a luminous arch is produced by the rays of each colour at its appropriate distance. The rays which never enter the drops produce no other effect, than to cause a brightness, or haziness round the sun, where the reflection is the most oblique: those which are once reflected within the drop exhibit the common internal or primary rainbow, at the distance of about forty-one degrees from the point opposite to the sun; those which are twice reflected, the external or secondary rainbow, of fifty-two degrees; and if the effect of the light, three times reflected, were sufficiently powerful, it would appear at the distance of about forty-two degrees from the sun. The colours of both rainbows encroach considerably on each other; for each point of the sun may be considered

as affording a distinct arch of each colour, and the whole disk as producing an arch about half a degree in breadth for each kind of light; so that the arrangement nearly resembles that of the common mixed spectrum. There is, however, another cause of a further mixture of colours: the arch of any single colour, which belongs to any point of the sun, is accurately defined on one side only, while on the other it becomes gradually fainter, the breadth of the first minute containing about five times as much light as a minute at the distance of a quarter of a degree: the abrupt termination is on the side of the red, that is, without the inner bow, and within the outer; so that, for this reason, the order of colours partakes, in some degree, of the nature of the red termination of a broad beam of light seen through a prism; but it is more or less affected by this cause, on account of some circumstances, which will be explained when we examine the supernumerary rainbows, which sometimes accompany the bows more commonly observed. A lunar rainbow is much more rarely seen than a solar one, but its colours differ little, except in intensity, from those of the common rainbow.

In the highest northern latitudes, where the air is commonly loaded with frozen particles, the sun and moon usually appear surrounded by halos, or coloured circles, at the distances of about twenty-two and forty-six degrees from their centres; this appearance is also frequently observed in other climates, especially in the colder months, and in the light clouds which float in the highest regions of the air. The halos are usually attended by a horizontal white circle, with brighter spots, or parhelia, near their intersections with this circle, and with portions of inverted arches of various curvatures; the horizontal circle has also sometimes anthelia, or bright spots, nearly opposite to the sun. These phænomena have usually been attributed to the effect of spherical particles of hail, each having a central opaque portion of a certain magnitude, mixed with oblong particles, of a determinate form, and floating with a certain constant obliquity to the horizon. But all these arbitrary suppositions, which were imagined by Huygens, are in themselves extremely complicated and improbable, and are wholly unauthorised by observation. A much simpler, and more natural, as well as more accurate explanation, which was suggested at an earlier period by Mariotte, had long been wholly forgotten, until

the same idea occurred to me, without any previous knowledge of what Mariotte had done. The natural tendency of water to crystallize, in freezing, at an angle of sixty degrees, is sufficiently established, to allow us to assume this as the constant angle of the elementary crystals of snow, which are probably either triangular or hexagonal prisms: the deviation produced by such a prism differs very little from the observed angle at which the first circle is usually seen; and all the principal phænomena, which attend this circle, may be explained, by supposing the axis of the crystals to assume a vertical or a horizontal position, in consequence of the operation of gravity: thus the parhelia, which are sometimes a little more distant from the sun than the halo, are attributed by Mariotte to the refraction of the prisms, which are situated vertically, and produce a greater deviation, on account of the obliquity of the rays of light with respect to their axis. The horizontal circle may be deduced from the reflection, or even the repeated refractions, of the vertical facets; the anthelia from two refractions with an intermediate reflection, and the inverted arch from the increase of the deviation, in the light passing obliquely, through prisms lying in a horizontal position. The external circle may be attributed either to two successive refractions through different prisms; or with greater probability, as Mr. Cavendish has suggested to me, to the effect of the rectangular terminations of the single crystals. The appearance of colours, in halos, is nearly the same as in rainbows, but less distinct; the red being nearest to the luminary, and the whole halo being externally very ill defined.

From the observed magnitude of these halos, I had concluded that the refractive power of ice must be materially less than that of water, although some authors had asserted that this was greater: and Dr. Wollaston afterwards fully confirmed this conclusion, by means of the very accurate instrument which has already been described; his measurement agreeing precisely with the mean of the best observations on these halos, so that ice must be considered as the least refractive of any known substances not aëriform.

Sometimes the figures of halos and parhelia are so extremely complicated as to defy all attempts to account for the formation of their different parts; but if we examine the representations which have been given, by various authors, of the multiplicity of capri-

cious forms frequently assumed by the flakes of snow, we shall see no reason to think them inadequate to the production of all these appearances.

[*Young's Nat. Phil. Vol. 1.*

It is in his second volume that Dr. Young has favoured us with his abstract of Dr. Wollaston's observations on the quantity of horizontal refraction, which is as follows.

Dr. Wollaston notices Mr. Monge's Memoir on the Mirage, observed in Egypt, as containing facts which fully agree with his own theory formerly published. From his observations on the degree of refraction produced by the air near the surface of the Thames, it appears that the variations derived from changes of temperature and moisture in the atmosphere, are by no means calculable; but that a practical correction may be obtained, which for nautical uses, may supersede the necessity of such a calculation. Dr. Wollaston first observed an image of an oar at a distance of about a mile, which was evidently caused by refraction, and when he placed his eye near the water, the lower part of distant objects was hidden, as if by a curvature of the surface. This was at a time when a continuation of hot weather had been succeeded by a colder day, and the water was sensibly warmer than the atmosphere above it. He afterwards procured a telescope, with a plane speculum placed obliquely before its object glass, and provided with a micrometer, for measuring the angular depression of the image of a distant oar, or other oblique object; this was sometimes greater when the object glass was within an inch or two of the water, and sometimes when at the height of a foot or two. The greatest angle observed was somewhat more than nine minutes, when the air was at 50°, and the water at 63°; in general the dryness of the air lessened the effect, probably by producing evaporation, but sometimes the refraction was considerable, notwithstanding the air was dry. Dr. Wollaston has observed but one instance which appeared to encourage the idea, that the solution of water in the atmosphere may diminish its refractive power.

In order to correct the error, to which nautical observations may be liable, from the depression of the apparent horizon, in consequence of such a refraction, or from its elevation in contrary circumstances; and at the same time to make a proper correction for

Engraved by Hay, from a Drawing by Craig

For the Gallery of Nature & Art

TWO MOCK SUNS.

London, Published by R.N. Rose, 46 Holborn Hill, May 1. 1820

the dip, Dr. Wollaston recommends that the whole vertical angle between two opposite points of the horizon, be measured by the back observation, either before or after taking an altitude; and that half its excess above 180° be taken for the dip: or if there be any doubt respecting the adjustment of the instrument, that it be reversed, so as to measure the angle below the horizon, and that one-fourth of the difference of the two angles, thus determined, be taken as extremely near to the true dip. It is indeed possible, that the refraction may be somewhat different at different parts of the surface; but Dr. Wollaston is of opinion that this can rarely happen, except in the neighbourhood of land.

[*Id. Vol. II. Journ. Royal Instit.*

SECTION V.

Parhelia, or Mock Suns, seen at Dantzic.

By M. Hevelius.

On February 5, 1674, N. S. near Marienburg in Prussia, I saw the sun, in a sky every where serene enough, being yet some degrees above the horizon, and shining very bright, yet lancing out very long and reddish rays, 40 or 50 degrees towards the zenith. Under the sun towards the horizon, there hung a somewhat dilute small cloud, beneath which there appeared a mock sun of the same size, to sense, with the true sun; and under the same vertical, of a somewhat red colour. Soon after, the true sun more and more descending to the horizon, towards the said cloud, the spurious sun beneath it grew clearer and clearer, so as that the reddish colour in that apparent solar disk vanished, and put on the genuine solar light; and that the more, the less the genuine disk of the sun was distant from the false sun: till at length the upper true sun passed into the lower counterfeit one, and so remained alone.

This appearance being unusual, I took the freedom of imparting it unto you, especially since here the mock sun was not found at the side of the true sun, as it is wont to be in all parhelia seen by me, but perpendicularly under it; not to mention the colour, so different from that which is usual in mock suns; nor the great length of the tail, cast up by the genuine sun, and of a far more vivid and splendid light, than parhelia used to exhibit.

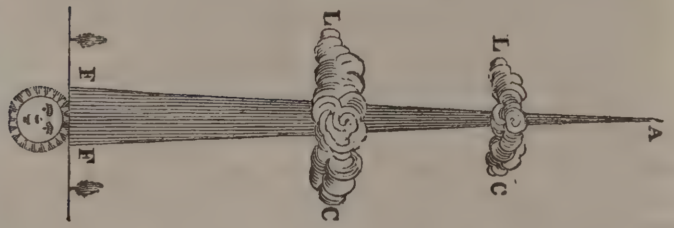
Upon this appearance there soon followed here an exceedingly intense and bitter frost, whereby the whole bay was frozen up from this town of Dantzic, as far as Hela in the Baltic sea, which lasted till the 25th of March; and the bay was frozen so hard, that with great safety people run out into it with sleds and horses, for several of our miles.

[*Phil. Trans.* 1674.

SECTION VI.

Pyramidal Appearance in the Heavens, observed near Upminster, Essex.

By the Rev. William Derham.



On the afternoon of Thursday, April 3, 1707, I perceived in the west, a quarter of an hour before sun-set, a long slender pyramidal appearance, perpendicular to the horizon. The base of this pyramid I judged to be the sun, then below the horizon. Its apex reached fifteen or twenty degrees above the horizon. It was throughout of a rusty red colour; and was, when I first saw it, pretty vivid and strong; but the top part much fainter than the bottom, nearer the horizon. At what time this appearance began, whether at, or how soon after sun-set, I cannot say, being at that time in a friend's house. But after a while, it grew by degrees weaker and weaker, so that in about a quarter of an hour after I first saw it, the top part (A, L, C,) was scarcely visible. But the lower part remained vivid much longer, but yet grew by degrees shorter and shorter. I saw the remains of the lower half (F, F,) a full hour after sun-set; and should perhaps have seen it longer, had the horizon been open, instead of which it was often in my walk obstructed by trees. The whole atmosphere seemed

hazy, and full of vapours, especially towards the sun-set. The moon and stars were bearded at that time, and succeeded with a halo about the moon afterwards; which disposition of the air was probably the cause of the phenomenon. But the pyramid was doubtless imprinted on the far distant vapours of the atmosphere, it being manifestly far off, or laying beyond some small thin clouds (C. L, C, L,) that intercepted it, and in those parts covered and hid it. I do not remember I ever saw any thing like it, except the white pyramidal glade, which is now called the aurora borealis. And it being, except in colour and length, so like that, I have thought it may perchance in some measure conduce to the solution of that old phenomenon, the aurora borealis.

[*Id.* 1707.

SECTION VII.

Parhelia at Sudbury, Suffolk.

By Mr. Petto.

August 28, 1698, about eight o'clock in the morning, there was seen the appearance of three suns, which were at the brightest then, or a little after. About half an hour after eight I saw it, when there was in the east a dark, dusky, watery cloud; and below it, towards the middle, was the true sun, shining with such strong beams, that persons could not look upon it; on each side were the reflections, with the true sun in the middle. Elsewhere much of the firmament was of an azure light blue colour. The circles which I saw were not of rainbow colours, but white; there was also higher in the firmament, more over our heads, and towards the south, at the same time, at a considerable distance from the other, the form of a half moon; but I think it was more than double the size of a half moon, with the horns turned upwards, and within of a fiery red colour, and more like a rainbow colour; these all faded gradually, after having continued about two hours.

[*Phil. Trans.* 1699.

SECTION VIII.

Two Mock-Suns, and an Arc of a Rainbow inverted, with an Halo.

By the Rev. William Whiston.

About ten o'clock in the morning, on Sunday, Oct. 22, 1721, being at Lyndon, in the county of Rutland, after aurora borealis the night before, wind W. S. W. I saw an attempt towards two mock-suns, as I had done sometimes formerly. About half or three quarters of an hour after, I found the appearance complete; when two plain parhelia, or mock-suns, appeared tolerably bright and distinct; and that in the usual places, viz. in the two intersections of a strong and large portion of a halo, with an imaginary circle, parallel to the horizon, passing through the true sun. This circle I call imaginary, because it was not itself visible, as it sometimes has been at such appearances. Each parhelion had its tail of a white colour, and in direct opposition to the true sun; that towards the east was 20 or 25° long; that towards the west about ten or twelve degrees; but both narrowest at the remote ends. The mock-suns were evidently red towards the sun, but pale or whitish at the opposite sides, as was the halo also. Looking upward, we saw an arc of a curious inverted rainbow, about the middle of the distance between the top of the halo and the vertex. This arc was as distinct in its colours as the common rainbow, and of the same breadth. The red colour was on the convex, and the blue on the concave of the arc; which seemed to be about 90° long: its centre in or near the vertex. On the top of the halo was a kind of inverted bright arc, though its bend was not plain. The lower part of the halo was among the vapours of the horizon, and not visible. The angles, as more exactly measured on Monday, near noon, when the same appearance returned again, but more faintly, were as follow: the sun's altitude $22\frac{1}{3}°$; perpendicular semidiameter of the halo $23\frac{1}{3}$; distance of the rainbow from the top of the halo $23\frac{1}{3}°$; semidiameter of the arc of the rainbow, if our vertex be supposed its centre, 21°. The phenomenon lasted each day for an hour and a half, or two hours. What was most remarkable on Monday was, that the wind, which on Sunday had been almost in-

sensible, was now become sensible, and changed to N. N. E. that the halo was sensibly become oval; its shorter axis parallel to the horizon; and the two mock-suns, which were then but just visible, especially that on the east, were not in the halo, but a degree or two without it, which I ascribe to the unusual shortness of the horizontal diameter; which position of the mock-suns does not appear to have been hitherto taken notice of by any, though it was now very sensible.

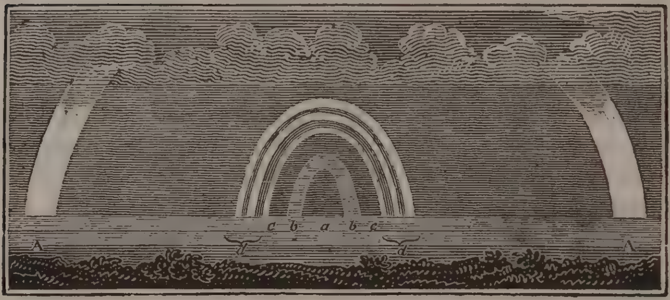
October 26, about nine in the morning, as I was coming in the Northampton coach towards London, the halo returned larger and clearer than before; and the two mock-suns just attempted an appearance, as on Sunday; but the air becoming thicker and thicker towards rain, I saw them no more. I add nothing to this account, but only, that August 30, before, I saw at the same place, Rutland, a remarkable halo, whose upper part had its inverted arc reddish within, and pale without, but brighter and more vivid than ever I saw before. That we had there, September 11, in the evening, the lightest and most remarkable aurora borealis, with its unaccountable motions and removals, that ever I saw, excepting that original one, March 6, 1711: that it was seen in Northamptonshire, at the Bath, and elsewhere: that the vertex of the columns which shot upwards, was not our vertex, but evidently fifteen or twenty degrees distant towards the south; and that the wind was in Rutland north, as I observed myself; at the Bath west; and in Northamptonshire south; all at the same time, which deserves particular reflection.

[*Id.* 1721.

SECTION IX.

Beautiful irridescent Arches in a Mist.

By Mr. William Cochin.



January 13, 1768, between nine and ten in the morning, being on an eminence that overlooked some low meadow-ground, Mr. Cochin observed, in a direction opposite to that of the sun, which shone very bright, and in a mist which covered the said inclosures, an unusual meteor, which, without attempting to name it, he describes by help of the above figure. At about the distance of half a mile, and incurvated towards each other, like the lower ends of the common rainbow, there appeared in the mist two places of a peculiar brightness, as represented at A A. They seemed, as is common, to rest on the ground, were continued as high as the mist, and in breadth near half as much more as that of the iris. In the middle, between these two places, on the same horizontal line, was a coloured appearance like d c b, a, b c d, whose base could not at most subtend an angle of above ten or twelve degrees, and whose interior parts were thus variegated. The centre *a* was dark and irregularly terminated, as if made by the shadow of some object not larger than an ordinary sheaf of corn. Next this centre was a curved space *b b*, of a yellowish flame-colour. To this succeeded another curved space of nearly the same dark cast as the centre, seemingly tinged with a faint blue green, and very evenly bounded on each side, as at *c c*. After those came on the terminating ring, which was coloured very much in the manner of the common rainbow, except that the tints were not quite so vivid (as if owing to the effect of a yellowish tinge, which seem-

ingly entered into the composition of all the colours) nor their boundaries so well defined. The centre of the image appeared to be exactly in the line of aspect, as it is called, or one conceived to be drawn from the sun through the eye of the spectator: and it may be observed from the figure, that these curve spaces were not segments of perfect circles, but formed like the ends of concentric ellipsis, whose transverse axis were perpendicular to the horizon.

To the above description of the image it may be necessary to add the following particulars which attended it. The mist was very thick near the surface of the meadows, though rarer upwards, and chiefly, if not solely, on the side of the hill opposite to the sun. The place where Mr. C. stood was just on its confines; and as he advanced into it, the object became gradually fainter and fainter. As the sun dispersed the vapour, the appearance faded proportionably; and about half an hour after he first saw it, it was scarcely visible. The evening before was wet; but the drops on the hedges were congealed by frost. Where the sun shone, the bushes were each invested with a mist, as if owing to the vapours exhaled from them by the sun's warmth; and, on a nearer inspection, he could clearly discern the little humid particles which occasioned it, and which were floating around the bushes at about half an inch distance from each other.

[*Id.* 1780.

SECTION X.

Peculiar solar and lunar Irises seen in South America.

To the before-mentioned particulars of the mountainous deserts, I shall subjoin the phenomena seen there, as subjects equally meriting the curiosity of a rational reader. At first we were greatly surprised with two, on account of their novelty; but frequent observations rendered them familiar. One we saw in Pambamarca, on our first ascent thither; it was a triple circular iris. At break of day the whole mountain was encompassed with very thick clouds, which the rising of the sun dispersed so far as to leave only some vapours of a tenuity not cognizable by the sight; on the opposite side to that where the sun rose, and about ten toises distant from the place where we were standing, we saw, as in a looking-glass, the image of each of us, the head being as it were the centre of the three concentric irises: the last or most external colours of one touched the first of the following; and at some distance from them all, was a fourth arch entirely white. These were perpendicular to the horizon; and as the person moved, the phenomenon moved also in the same disposition and order. But what was most remarkable, though we were six or seven together, every one saw the phenomenon with regard to himself, and not that relating to others. The diameter of the arches gradually altered with the ascent of the sun above the horizon; and the phenomenon itself, after continuing a long time, insensibly vanished. In the beginning, the diameter of

LUNAR RAINBOW SEEN AT MILBROOK NEAR SOUTHAMPTON.

at 10 o'Clock at Night Oct^{r}. 1810.

London, Published by R N Rose, [illegible] Holborn Hill, May 1, 1820.

the inward iris, taken from its last colour, was about five degrees and a half; and that of the white arch, which circumscribed the others, not less than sixty-seven degrees. At the beginning of the phenomenon, the arches seemed of an oval or elliptical figure, like the disk of the sun, and afterwards became perfectly circular. Each of the least was of a red colour, bordered with an orange: and the last followed by a bright yellow, which degenerated into a straw colour, and this turned to a green. But, in all, the external colour remained red.

On the mountains we also had frequently the pleasure of seeing arches formed by the light of the moon, particularly one on the 4th of April, 1738, about eight at night, on the plain of Turubamba. But the most singular one was seen by Don George Juan, on the mountain of Quinoa loma, on the 22d of May, 1739, at eight at night. These arches were entirely white, without the mixture of any other colour, and formed along the slope or side of a mountain. That which Don George Juan saw, consisted of three arches, touching in the same point: the diameter of the inner arch was sixty degrees, and the breadth of the white mark, or delineation, took up a space of five degrees; the two others were, in every respect, of the same dimensions.

The atmosphere, and the exhalations from the soil, seem more adapted than in any other place for kindling the vapours, meteors being here more frequent, and often very large, last longer, and are nearer the earth, than the like phenomena in other parts.

[*Ulloa's Voyage to South America.*

SECTION XI.

Lunar Rainbow in Derbyshire.

By Mr. Ralph Thoresby, F. R. S.

The iris lunaris being so rarely seen, that Dr. Plot tells us* that several learned and observing men never saw one in their lives; and that even Aristotle himself observed only two in above fifty years; the ensuing account, which I had from a gentleman of great veracity and ingenuity, will be the more acceptable. He was lately in Derbyshire, where, on Christmas last, he was at Glapwell Hall; and walking towards Patterson Green, about eight in the evening, he observed with great satisfaction the bow, which the moon had fixed in the clouds: she had then passed her full about

* Nat. Hist. of Oxford, chap. I, sec. 7.

twenty-fours hours; the evening had been rainy, but the clouds were dispersed, and the moon shone pretty clear. The iris was more remarkable than that which Dr. Plot observed at Oxford the 23d of November, 1675; that being only of a white colour, but this had all the colours of the solar iris, exceedingly beautiful and distinct, only faint in comparison of those we see in the day; as must necessarily be the case, both from the different beams that cause it, and the disposition of the medium. What puzzled him the most, was the largeness of the arc, which was not so much less than that of the sun, as the different dimensions of their bodies, and their respective distances from the earth seem to require: but as to its entireness and beauty of its colour, it was surprising. It continued about ten minutes, before the interposition of a cloud hindered his further observations. [*Phil. Trans.* 1711.

SECTION XII.

Description of a Glory seen on Mount Rhealt, near the vale of Clwyd.

By John Haygarth, M.B. F.R.S. &c.

On the 13th of February, 1780, as I was returning to Chester, and ascending, at Rhealt, the mountain which forms the eastern boundary of the Vale of Clwyd, I observed a rare and curious phenomenon. My ingenious friend Mr. Falconer has given, from my description, an exact representation of it, in a drawing which accompanies this paper.

In the road above me, I was struck with the peculiar appearance of a very white shining cloud, that lay remarkably close to the

ground. The sun was nearly setting, but shone extremely bright; I walked up to the cloud, and my shadow was projected into it. The head of my shadow was surrounded, at some distance, by a circle of various colours, whose centre appeared to be near the situation of the eye, and whose circumference extended to the shoulders. This circle was complete, except what the shadow of my body intercepted. It exhibited the most vivid colours. red being outermost: as far as can be recollected, all the colours appeared in the same order and proportion that the rainbow presents to our view It resembled, very exactly, what in pictures is termed a *glory*, around the head of our Saviour, and of saints: not indeed that luminous radiance, which is painted close to the head, but an arch of concentrate colours, which is placed separate and distinct from it. As I walked forward, this glory approached or retired, just as the inequality of the ground shortened or lengthened my shadow. The cloud being sometimes in a small valley below me, sometimes on the same level, or on higher ground, the variation of the shadow and glory became extremely striking and singular.

To add to the beauty of the scene, there appeared, at a considerable distance, to the right and left, the arches of a white shining bow. These arches were in the form of, and broader than a rainbow; but were not completely joined into a simicircle above, on account of the shallowness of the cloud. When my chaise came up, I could observe no peculiar appearance round the shadows of the postillion, horses, or chaise. But the postillion was alarmed, to an uncommon degree, by this very singular apparition; which, indeed, might excite terror, or delight, in the beholder, according to the disposition of mind with which it was viewed.

Several appearances have been described by philosophers, in some respects resembling what I saw, but not exactly the same. The arch in size, situation, and colour, was most exactly the glory represented in some pictures, and is manifestly the archetype whence it had been copied by a painter. Indeed such a phenomenon is well adapted to excite religious awe and reverence.

When I returned into the chaise, a bright radiance appeared close to its shadow, but no separate coloured circle was formed.

In order to investigate the cause of these curious appearances, on optical principles, it may be useful to note some peculiar circumstances. The cloud was specifically heavier than the air of that

region where it was placed; for it descended with considerable velocity down the side of the mountain. It was very close and shallow, being, in part, compressed by its own weight; the air at that altitude being too rare to suspend it.

I have seen at other times, but not frequently, clouds of the same appearance. On the 28th of November, 1780, I saw some clouds which exactly resembled those in which the glory was observed, but had not leisure to approach them. These were remarkably close, compact, and shallow on the mountain; but, in the adjoining valley (of Mold,) they were thin, rare, and deep. In the valley, the atmosphere and the clouds seemed to be of the same specific gravity. The cloud on the mountain had a shining brightness, where the sun shone upon it, but was extremely black where shaded by other clouds.

In some cases, the cloud in which a similar appearance has been observed, was thought to be composed of frozen particles. It probably was so in the present instance. For, some hours later, the same evening being on horseback, and passing through a thick cloud, icicles had formed on my hair, which by the motion of riding produced a sound like the ringing of distant bells.

No coloured arch like a rainbow, I believe, has ever appeared in a hail or snow shower: the frozen drops are probably too opake, too distant, and too large, to exhibit such colours. But the proximity and the minuteness of the frozen particles, in the cloud above described, might probably allow the rays of light to be reflected, and refracted in a coloured circle. Experiments on thin frozen surfaces, in a prismatic form, or on small frozen particles of water, might successfully illustrate this curious subject. Glass encrusted with ice may afford some observations. And the sun shining on a surface of snow, covered with a hoar-frost, exhibits, as I have lately remarked, beautiful brilliant points of various colours, as red, green, blue, &c. reflected and refracted at different angles; which, by attentive observation, might perhaps explain the cause both of the glory, and of the bright arches above described.

Explanation of the Drawing.

CC. The white cloud.
AA. The shining arches.
SS. The shadow.
GG. The glory.

[*Mem. of the Manchester Society.*

CHAP. XLIX.

ON SOUNDS AND ECHOES.

The phenomena of sound have in many instances a strong resemblance to those of light. Hook and Euler supposed both to consist in a mere vibration or impulse of ether, or of air. Newton contended for a peculiar luminous fluid, or matter of light, distinct from ether; and Epicurus for a peculiar sonorous fluid, or matter of sound, distinct from air; an opinion which Lamarck* appears to have revived in our own times. Light, as we have already seen, is subject to reflection and refraction, agreeably to definite laws; sound is subject to the same effects, and according to laws equally definite; and it is from this reflection and refraction that echoes or mock-voices, whispers, and confused murmurs, are produced, in the latter instances; as parhelia or mock-suns, rainbows, and halos in the former: the one is peculiarly affected by colours, on which the other altogether depends. EDITOR.

SECTION I.

General Observations on the Nature of Sound, whispering Domes, and Echoes.

Sound is propagated successively from the sounding body to the places which are nearer to it, then to those that are farther from it, &c.

A great many long and laborious calculations have been made by divers able philosophers and mathematicians, for the purpose of deducing the velocity of sound through the air, from the known weight, elasticity, and other properties of air; but the results of such calculations differ considerably from each other, as also from the results of actual experiments; which shews either that the calculations have been established upon defective principles, or that not all the concurring circumstances have been taken into the ac-

* Journal Physique, lxix. 397.

count. Therefore, without mentioning any thing farther with respect to those calculations, I shall immediately state the result of authentic and useful experiments.

Almost every body knows, that when a gun is fired at a considerable distance from him, he perceives the flash a certain time before he hears the report; and the same thing is true with respect to the stroke of a hammer, of an hatchet, with the fall of a stone, or, in short, with any visible action which produces a sound or sounds. The time which sound employs in its motion through the common air, has been measured by various ingenious persons. The principal, and more general method has been, to measure (by means of a stop-watch or a pendulum) the time which elapses between the appearance of the flash and the hearing of the report of a gun fired at a certain measured distance from the observer; for light travels so fast through the distance of 1000 or 2000 miles, that we cannot possibly perceive the time; therefore we may conclude that the explosion of a gun takes place at the very same moment in which we perceive the flash.

In the first place it has been unanimously observed, that sound travels at an uniform rate; viz. that it will go as far again in two seconds as it will in one second; that it will go three times as far in three seconds, or four times as far in four seconds, as it will in one, and so on. Therefore, in the above-mentioned manner of performing the experiment, if the distance, (in feet) between the cannon and the observer, be divided by the number of seconds elapsed between the perceptions of the flash and of the report, the quotient will shew the rate of travelling, or how many feet per second sound runs through.

This rate has been estimated differently by different persons, whose experiments have been performed at different times, in different places, and with instruments more or less accurate, viz.

	Feet per Second.
* By Sir Isaac Newton, at the rate of..................	968
† By the Hon. Mr. Roberts, at	1300
‡ By the Hon. Mr. Boyle, at	1200
§ By Mr. Walker, at	1338

* Principia. B. II. Prop. 50.

† Phil. Trans. No. 209.

‡ Essay on Motion.

§ Phil. Trans. No. 247.

* By Mersennus, at	1474
† By the Florentine Academicians	1148
‡ By the French Academicians	1172
§ De Thury, Maraldi, and de la Caille	1107
‖ Flamstead, Halley, and Derham, at	1142

Dr. Derham, as it appears by the account in the Philosophical Transactions, seems to have made the greatest number of accurate and more diversified experiments; therefore we may take his conclusion, which coincides with those of Flamstead and Halley, as the nearest to the truth; viz. that, in general, sound travels uniformly through the atmospherical air at the rate of 1142 feet per second, or one mile in little less than five seconds; at least, this result cannot differ from the truth by more than fifteen or twenty feet ¶. But it will appear from the following paragraphs, and from the difficulty of measuring time to a fraction of a second, that no very great degree of accuracy can be expected in measurements of this sort.

Derham observed, that the report of a cannon fired at the distance of thirteen miles from him, did not strike his ears with a single sound, but that it was repeated five or six times close to each other. "The two first cracks," he says, "were louder than the third, but the last cracks were louder than any of the rest.—And besides, in some of my stations, besides the multiplied sound, I plainly heard a faint echo, which was reflected by my church, and the houses adjacent."

This repetition of the sound probably originated from the reflection of a single sound from hills, houses, or other objects, not much distant from the cannon. But it appears from general observation, and where no echo can be suspected, that the sound of a cannon, at the distance of ten or twenty miles, is different from the sound when near. In the latter case the crack is loud and

* Balistic. Prop. 39. † Exp. of the Acad. del Cimento, p. 141.

‡ Du Hamel Hist. Acad. Reg.

§ They reckoned it equal to 173 toises, which are nearly = to 1107 feet English. See Mem. de l'Acad. for 1738, p. 128, &c.

‖ Phil. Trans. Jones's Abrid. vol. iv. p. 396.

¶ According to Mr. Hale, the undulation of water is to the motion of sound as one to 865.

instantaneous, of which we cannot appreciate the height. Whereas in the former case, viz. at a distance, it is a grave sound, which may be compared to a determinate musical sound; and instead of being instantaneous, it begins softly, swells to its greatest loudness, and then dies away growling. Nearly the same thing may be observed with respect to a clap of thunder. Other sounds are likewise altered in quality by the distance.

Upon the whole, it appears that the velocity of sound is exactly the same, whether the sound be high or low, strong or feeble, whether it be the sound of a human voice, or the report of a cannon. But its velocity is sensibly altered by winds. If the wind conspires with the sound, viz. if it blows in the direction from the sounding body to the hearer, the sound will be heard sooner; and if the wind blows the contrary way, the sound will be heard later, than according to the rate of 1142 feet per second. In short, the velocity of the wind, in the former case, must be added to, and in the latter it must be subtracted from, that of the sound *. But the velocity of the air in the strongest wind is, perhaps, not equal to the twentieth part of the velocity of sound.

Heat and cold seem to make a very small alteration in the velocity of sound; for sound appears to travel a little faster in summer than in winter.

Different altitudes of the barometer, as also different quantities of moisture in the air, seem to occasion a small alteration in the velocity of sound. But it is not in our power to determine what share of the effect is due to each of those causes.

Upon the whole it appears, that whatever increases the elasticity of the air, accelerates the motion, as also the intensity of sound through it, and *vice versa*. Or, in fluids of a determinate elasticity, whatever increases the density, diminishes the velocity of sound through them. Probably the velocities of sound through

* The knowledge of this fact will enable us to measure, pretty nearly, the velocity of the wind in certain cases; for if a cannon be fired at a known distance from us, the report must reach us sooner when the wind blows from that place to us, and later when it blows the contrary way, than it will in calm weather; therefore, knowing what time it ought to reach us in calm weather, the difference between that time and the time observed in the above-mentioned cases of windy weather, is the time which the wind employs in passing through that distance.

such fluids, are as the square roots of the densities. Experience seems to prove, that at different times of the year (the influence of the winds being excluded) the velocity of sound may be faster or slower, not exceeding thirty feet, than at the above-mentioned mean rate of 1142 feet per second.

The knowledge of the velocity of sound through the air, may be applied to a very useful purpose, viz. to the measurement of distances, especially when no better method can be be used with conveniency. Thus we may measure the distance of a thunder cloud, by measuring the time which elapses between the appearance of the flash of lightning and the report of the explosion or thunder; for, if by looking on a clock or a watch with a second's hand, we find that the time elapsed is one second, we may conclude that the explosion took place at the distance of 1142 feet from us; if the elapsed time be two, or three, or any other number of seconds, we may conclude that the distance is the product of 1142 multiplied by two, or by three, or by the other number of seconds. After the same manner, by observing the flash and the report of a gun, or the motion of the hand which moves a hammer, and the perception of the sound, &c. we may determine, pretty nearly, the distance of a ship, or of an island, or of a workman, &c.

Air is always around us, and therefore is the most common medium through which sounds are transmitted: but sounds may also be convoyed by other bodies, both solid and fluid; viz. by water, by metals, by wood, by stones, by ropes, &c. and in most cases more readily, and more perfectly, than by the air. Probably there is no substance which is not in some measure a conductor of sound; but sound is much enfeebled by passing from one medium to another.

If a man stops one of his ears with his finger, stops the other ear by pressing it against the end of a long stick, and a watch be applied to the opposite end of the stick, or of a piece of timber, be it ever so long, the man will hear the beating of the watch very distinctly; whereas in the usual way through the air, he can hardly hear it from a greater distance than about fifteen feet.

The same effect will take place if he stops both his ears with his hands, and rests his teeth, his temple, or the cartilaginous part of one of his ears, against the end of the stick. Instead of a stick he

may use a rod of iron, or other metal, a block or pillar of marble, &c.

Instead of applying the watch, a very gentle scratch may be made at one end of a pole, or rod, and the person who keeps the ear in close contact with the other end of the pole, after the above-mentioned manner, will hear it with great accuracy.

Thus persons who are not quick of hearing, by applying their teeth to some part of a harpsichord, or other sounding body, will, by that means, be enabled to hear the sound much better than otherwise.

If a man stops his ears with his hands, then passes the loop of a string (which has a piece of metal, as a spoon, &c. tied to its extremity) over his head and hands, and by stooping himself a little, keeps the end of the string, with the spoon or piece of metal pendant before him; on striking the spoon against any thing, he will hear a sound not much different from that of a large bell. Such experiments are capable of great variety*.

It has been said, that the reports of cannon fired at Toulon may be heard at Monoco, viz. at the distance of about seventy-six miles, by a person lying on the ground, but not otherwise. But the practice of placing one's ear close to the ground, in order to perceive the approach of horses or men; or, in short, for the purpose of hearing distant sounds, has been observed even amongst uncivilized nations.

Articulate sounds may also be transmitted through solids; but I must own, they are not perceived very distinctly by my ear. However, Dr. Chladni, who has made a vast number of experiments relative to this subject, expresses himself in the following manner:

"Articulated tones also are conducted exceedingly well through hard bodies, as I found by experiments which I made with some of my friends. Two persons who stopped their ears, could converse with each other when they held a long stick, or a series of sticks, between their teeth, or rested their teeth against them. It is all the same whether the person who speaks rests the stick against his throat or his breast, or whether one rests the stick which he holds in his teeth against some vessel into which the other speaks.

* See the Mem. of the Ac. of Turin, for 1790 and 1791.

The effect will be greater the more the vessel is capable of a tremulous movement. It appeared to be strongest with glass and porcelain vessels; with copper kettles, wooden boxes, and earthen pots, it was weaker. Sticks of glass, and next fir-wood, conducted the sound best. The sound could also be heard when a thread was held between the teeth by both, so as to be somewhat stretched. Through each substance, the sound was modified in a manner a little different. By resting a stick or other body against the temples, the forehead, and the external cartilaginous part of the ear, sound is conveyed to the interior organs of hearing; as will readily appear, if you hold your watch to those parts of another person who has stopped up his ears. From this it appears, as well as from the experiments relative to the hearing under water, that hearing is nothing else than, by means of the organs of hearing, to be sensible of the tremulous movement of an elastic body, whether this tremulous movement be conveyed through the air, or any other fluid or hard body, to the auricular nerves. It is also essentially the same whether, as is usually the case, the sound be conveyed through the internal part of the ear, or whether it be communicated through any other part of the body. It certainly would be worth the trouble to make experiments, to try whether it might not be possible that deaf and dumb people, when the deficiency lies only in the external organs of the ear, the auricular nerve being perfect, could not, by the above method of conducting sound, be made to hear, distinctly, words articulated, as well as other sounds*."

The velocity with which sound moves through solids, is by no means known, nor does it seem likely to be determined experimentally; for such experiments can only be performed with several hundred feet length of each particular substance. The only thing which has been tried relative to this subject, is to transmit a sound through a series of pieces of wood placed in close contact the first with the second, the second with the third, and so on. It was found that sound was transmitted through wood faster than through air; but it could not be determined how much faster†.

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* This has been taken from the Phil. Mag. for July 1799, which contains the translation of some passages extracted from Dr. Chladni's original work on the longitudinal vibrations of strings, &c.

† By reasoning and calculation it has been deduced, that a column of air

Whether sound be transmitted at all through vacuum or not, is by no means determined. A bell inclosed in a glass receiver, and caused to sound, can be heard less and less, according as the glass is more and more exhausted of air; but though I have used one of the best air-pumps that was ever constructed, and the apparatus which supported the bell was laid upon such soft substances as seemed least likely to transmit the sound through them; yet I could never render the sound of the bell quite inaudible. Besides, it may be suspected, that when the glass receiver is exhausted of air, the pressure of the atmosphere, on its outside only, may check in great measure the transmission of the sound. If it be asked what can transmit the sound, or the vibrations of the bell, when the air between it and the glass has been removed, supposing that it might be entirely removed? we must undoubtedly assert our ignorance of it. But our ignorance of what may transmit the sound in that case, does not prove that the sound could not be heard, if the air were entirely removed.

Sounds diminish in intensity, or they are less audible, according as the hearers are farther from the sounding body; but there is no accurate method of determining this decrease*.

The same sound is stronger in dense than in thinner air. The actual fall of rain, snow, &c. or a good deal of moisture in the air, diminishes the intensity of sound. In calm, serene weather, when every thing is quiet, a sound is heard much stronger, and of course much farther than otherwise. When a smooth surface of ground, and especially of water, is interposed between the sounding body and the hearer, then sounds may be heard much farther than when water much agitated, or ground covered with houses, trees, &c. is interposed.

In favourable circumstances the striking of the clock on the bell

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in a pipe of a certain length, open at both ends, makes one longitudinal vibration in the same time that sound would employ to percur the same length of air; *(Riccati delle fibre elastiche.* Newton's Princ. L. 2. Prop. 50.) hence it may be presumed, by analogy, that sound is transmitted by solids of a certain length, in the same time in which those solids would perform each of their longitudinal vibrations. Now it has been found that a rod of iron of a certain length, will perform its longitudinal vibrations much faster than an equal pillar of air; therefore it is likely that sound will move through iron much faster than through air; and the same thing may be said of other solids.

* See the Phil. Trans. for 1800, p. 120.

of St. Paul's church, in London, has been heard in Windsor. It has been said, that with a particular concurrence of favourable circumstances, the human voice has been heard at the distance of more than ten miles, viz. from Old Gibraltar to New Gibraltar*. The discharge of an ordinary musket can hardly ever be heard farther than seven or eight miles; but the discharge of several such muskets at the same time may be heard from a greater distance. The quick repetition of the same sound may also be heard somewhat farther than the same singly. In the Dutch war of the year 1672, it has been said, that the reports of cannons were heard at the distance of 200 miles, and upwards.

It is commonly said, that the vibrations, which are communicated to the air by a sounding body, expand spherically all round that body; and in fact its sound may be heard on any side of it; yet certain it is, that the sound will not be heard with equal force and distinction in every direction; and this difference is much greater with certain sounding bodies, (viz. when a strong impulse is given to the air in a particular direction) than with others. The report of a cannon appears louder to a person towards whom it is fired, than to one situated in a contrary direction†. The speaking-trumpet throws the sound directly before its aperture, and very little of it can be heard by persons who are out of that direction‡. In windy weather the sound of a distant bell is perceived to increase or decrease

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* Derham's Physico-Theology, B. iv. chap. 3. See also the Phil. Trans. No. 300, for more facts of this nature.

† Phil. Trans. for 1800, p. 118.

‡ Upon this principle several curious contrivances may be made; and the speaking of the inanimate figure, suspended in the air, which was exhibited in London some years ago, depends upon the same principle. The mechanism was as follows: a wooden figure was suspended in the air by means of ribbands, in an opening between two rooms. There was a perforation about an inch and a half in diameter, from the mouth to the upper part of the head. This aperture had an enlarged termination on the top of the head, and with the other extremity communicated with a sort of speaking-trumpet, which was fastened to the mouth of the figure. Behind the partition the enlarged or funnel-like opening of a tube was situated directly opposite to, and at about two feet distance of, the aperture on the head of the figure. The tube behind the partition was bent in a convenient form, and a concealed performer applied either his mouth or his ear to the other end of the tube. Now, if a person applied his mouth to the opening of the trumpet, and spoke into it, the sound passed from the opening on the head of the figure through the air, to the opening of the tube which stood facing it behind the partition of the rooms, and

in loudness, according as the wind alters its strength or its direction. An obstruction to the direction of sounds is evidently made by hills, houses, large trees, and other bodies of a certain extent; for the sound of a distant bell, of a mill, of the waves of the sea on the shore, &c. may be heard much better when nothing solid is interposed between the hearer and the sounding body, than otherwise. This may be easily observed by a person walking through a town, when a noise proceeds from any of the above-mentioned causes; for he will hear the noise much better when he comes to the opening of a street which leads to the sounding place, than when the houses intervene; so that the sound which comes out of an aperture, does not expand spherically round that aperture, as round a centre; and this is analogous to what has been said with respect to the direction of a stream of water, which comes out of an aperture; but it must be confessed, that we are less able to comprehend the real motion of the air, than that of the waves on the surface of the water, or that of a stream.

Sounds are also reflected by hard bodies, and this reflection produces the well-known phenomenon called *echo;* and other analogous to it.

If a person standing at a certain distance before a high wall, a bank, a rock, &c. utters a word or makes a noise, either with his voice, or with a hammer, &c. he will frequently hear a repetition of the word or other noise; and the time which elapses between the expression of the sound, and the hearing of the same again, is the same as sound in general would employ in going twice through the distance between the man and the wall, or the rock, &c. for the vibrations of the air must go from the man to the wall, and back again; so that if the wall be 1142 feet distant, the time elapsed between the expression of the sound, and the second arrival of it to the ear, will be two seconds; and so forth.

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the person, who applied his ear to the further opening of the tube, would hear it distinctly; but other persons in the room heard very little, if at all, of the said articulated sound; and the same thing took place, when the concealed person spoke with his mouth close to the farthest end of the tube, and another person placed his ear close to the opening of the trumpet; which shews that the sound passed almost entirely in a straight direction, from the opening on the head, to the opposite aperture of the tube, and *vice versa.* This made it appear as if the wooden figure itself comprehended words, and returned an adequate answer.

But the same original sound, and the repetition of it, which is called the echo, may be heard by other persons situated at different distances both from the original sounding place, and from the reflecting wall, or other object. The effect, however, will not be exactly alike; for instance, those who are nearer to the wall, will hear the echo sooner than other persons; those who are as far again from the man who expresses the sound, as they are from the reflecting obstacle, when the reflecting object is at an equal distance from both, will hear both the original sound and the echo at the same time; in which case they will perceive, as it were, one sound louder than they would without the repetition.

But though several persons in different situations will hear the echo, or repetition of the same sound; yet in a particular direction, the echo may be heard much better than in other directions. Now, if two straight lines be drawn from the centre or middle of the reflecting surface, one to the place whence the original sound proceeds, and another in the above-mentioned best direction; those lines will be found to make equal angles with, or to be equally inclined to that surface. Hence it is said, "that sound is reflected by certain bodies, and that the angle of reflection is equal to the angle of incidence."

This shews, that though sound proceeds from an original sounding body, or from a reflecting surface, in every direction; yet a greater quantity of it proceeds in some particular direction than in any other; and this is probably owing to the original impulse being given to the air in one direction more forcibly than in others, as also to the want of perfect freedom of motion in the aërial fluid.

The surface of various bodies, solids as well as fluids, have been found capable of reflecting sounds, viz. the sides of hills, houses, rocks, banks of earth, the large trunks of trees, the surface of water, especially at the bottom of a well, and sometimes even the clouds. It is therefore evident, that in an extensive plain, or at sea, where there is no elevated body capable of reflecting sounds, no echo can be heard.

The configuration of the surface of those bodies seems to be much more concerned in the production of the echo, than the substance itself. A smooth surface reflects sounds much better than a rough one. A convex surface is a very bad reflector of sound; a flat surface reflects it very well; but a small degree of concavity, and

especially when the sounding body is in the centre, or focus of the concavity, renders that surface a much better reflector.

Thus in an elliptical chamber, if the sounding body be placed in a focus of the ellipsis, that sound will be heard much louder by a person situated in the other focus, than in any other part of the chamber. In this case the effect is so powerful, that even when the middle part of the chamber is wanting, viz. when the two opposite elliptical shells only exist, the sound expressed in one focus will be heard by a person situated in the other focus, but hardly at all by other persons *.

This in some measure explains the effect of what are called *whispering domes*, and *whispering galleries;* wherein, if a person speaks pretty near the wall on one side of it, another person will hear him distinctly when he places his ear pretty near the wall on the opposite side. The dome in St. Paul's cathedral, in London, has this curious property, which is generally shewn to all enquiring visitors.

Several phænomena may be explained so easily upon the above-mentioned theory of the reflection of sound, that they need be merely mentioned to the intelligent reader.

Several reflecting surfaces frequently are so properly situated, with respect to distance and direction, that a sound proceeding from a certain point, is reflected by one surface first, then by another which is a little farther off, after which it is reflected by a third surface, and so on; or it is reflected from one surface to a second, from the second to a third, from the third to a fourth, &c. Hence, echoes, which repeat the same sound, or the same word, two or three, or several times over, are frequently met with.

According to the greater or less distance from the speaker, a reflecting object will return the echo of several, or of fewer syllables; for all the syllables must be uttered before the echo of the first syllable reaches the ear, otherwise it will make a confusion. In a moderate way of speaking, about $3\frac{1}{2}$ syllables are pronounced

* If from any point in the circumference of an ellipsis, two lines be drawn to the foci, those lines make equal angles with the curve at that point. This is demonstrated by all the writers on conics. Therefore, the sound which is produced in one focus of an elliptical chamber, and is reflected from the wall to the other focus, makes all the angles of incidence equal to the angles of reflection respectively. Hence, that focus is the place where the sound is heard best.

in one second, or seven syllables in two seconds*. Therefore, when an echo repeats seven syllables, the reflecting object is 1142 feet distant; for sound travels at the rate of 1142 feet per second, and the distance from the speaker to the reflecting object, and again from the latter to the former, is twice 1142 feet. When the echo returns fourteen syllables, the reflecting object must be 2282 feet distant, and so on. A famous echo is said to be in Woodstock Park, near Oxford. It repeats seventeen syllables in the day, and twenty at night †. Another remarkable echo is said to be on the north side of Shipley church, in Sussex. It repeats distinctly, in favourable circumstances, twenty-one syllables ‡.

Therefore the farther the reflecting surface is, the greater number of syllables the echo will repeat; but the sound will be enfeebled nearly in the same proportion, and at last the syllables cannot be heard distinctly.

When the reflecting object is too near, the repetition of the sound arrives at the ear, whilst the perception of the original sound still continues, in which case an indistinct resounding is heard. This effect may be frequently observed in empty rooms, passages, &c. especially because in such places several reflections from the walls to the hearer, as also from one wall to the other, and then to the hearer, clash with each other, and increase the indistinction.

If each of the vibrations of the air, which are occasioned by a certain sound, be performed in the same time that sound employs in going from the sounding body to the walls of a room, and thence to the hearer, then the sound will be heard with greater force. In short, by altering our situation in a room, and expressing a sound, or hearing the sound of another person, in different situations, or when different objects are alternately placed in the room, that sound may be heard louder or weaker, and more or less distinct. Hence it is, that blind persons, who are under the necessity of paying great attention to the perceptions of their sense of hearing, acquire the habit of distinguishing, from the sound even of their

* From the computation of short-hand writers, it appears that a ready and rapid orator in the English language, pronounces from 7000 to 7500 words in an hour, viz. about 120 words in a minute, or two words in each second.—Memoirs of Gibbon's Life.

† Dr. Plot's Nat. Hist. of Oxfordshire.

‡ Harris's Lex. Tech. Article Echo.

own voices, whether a room is empty or furnished, whether the windows are open or shut; and sometimes they can even distinguish whether any person be in the room or not*.

[*Cavallo's Philos.*

SECTION II.

Extraordinary Whispering-places and Echoes.

In a Letter from Robert Southwell, Esq. dated September 19, 1661.

The best whispering-place I ever saw was that at Gloucester: but in Italy, in the way to Naples, two days from Rome, I saw, in an inn, a room with a square vault, where a whisper could be easily heard at the opposite corner, but not at all in the side corner that was near to you.

I saw another, in the way from Paris to Lyons, in the porch of a common inn, which had a round vault; but neither of these were comparable to that of Gloucester; only the difference between these two last was, that to this, holding your mouth to the side of the wall, several could hear you on the other side; the voice being more diffused. But to the former, it being a square room, and you whispering in the corner, it was only audible in the opposite corner; and not to any distance from thence as to distinction of words. And this property was common to each corner of the room, and not confined to one.

As to echoes, there is one at Bruxelles that answers fifteen times; but when at Milan, I went two miles from thence to a nobleman's palace. The building is of some length in the front, and has two wings jetting forward; so that it wants only one side of an oblong figure. About 100 paces before the house, there runs a small brook, and that very slowly; over which you pass from the house into the garden. We carried some pistols with us, and, firing one

* The famous Dr. N. Saunderson, professor of mathematics in the university of Cambridge, who had been blind since he was one year old, possessed such acuteness of hearing, that, as is related in the account of his life, "By his quickness in this sense, he not only distinguished persons with whom he had ever once conversed, so long as to fix in his memory the sound of their voice, but in some measure places also. He could judge of the size of a room into which he was introduced, of the distance he was from the wall: and if ever he had walked over a pavement in courts, piazzas, &c. which reflected a sound, and was afterwards conducted thither again, he could exactly tell whereabouts in the walk he was placed, merely by the note it sounded."

of them, I heard fifty-six reiterations of the noise. The first twenty were with some distinction; but then, as the noise seemed to fly away, and answer at a greater distance, the repetition was so doubled, that you could hardly count them all, seeming as if the principal sound was saluted in its passage by reports on this and that side at the same time. Some of our company reckoned above sixty reiterations when a louder pistol was discharged.

[*Phil. Trans.* 1746.

SECTION III.

Singular sympathetic action of two Pendulum Clocks on each other.

By Mr. John Elliscott, F.R.S.

The two clocks, on which the following observations were made, being designed for regulators, particular care was taken to have every part made with all possible exactness: the two pendulums were hung in a manner different from what is usual; and so disposed, that the wheels might act on them with more advantage. Upon trial, they were found not only to move with greater freedom than common, but a heavier pendulum was kept in motion by a smaller weight. They were in every respect made as near alike as possible. The ball of each of the pendulums weighed above 23lb.; and required to be moved about $1^{\circ} 5'$ from the perpendicular, before the teeth of the swing-wheel would scape free of the pallets; that is, before the clocks would be set a-going. The weight to each was 3lb. which would cause either of the pendulums in their vibrations to describe an arch of 3°. The two clocks were in cases, which shut very close, and placed sideways to each other, so near that when the pendulums were at rest, they were little more than about two feet asunder.

The odd phænomena observed in them were these: in less than two hours after they were set a-going, one of them, called No. 1, was found to stop; and when set a-going again, as it was several times, it would never continue going four hours together. As it had always kept going with great freedom, before the other clock, No. 2, was placed near it, this led Mr. E. to conceive its stopping must be owing to some influence the motion one of the pendulums had upon the other; and on watching them more narrowly, the motion of No. 2 was found to increase as No. 1 diminished; and

at the time that No. 1 stopped, No. 2 described an arch of 5°; that is, two degrees more than it would have done, if the other had not been near it, and more than it moved in a short time after the other pendulum came to be at rest: this made Mr. E. imagine that they had a mutual influence on each other.

On this he stopped the pendulum of No. 2, leaving it quite at rest, and set No. 1 a-going, the pendulum describing as large an arch as the case would permit, viz. about 5°. In about twenty minutes after, he went to observe whether there was any motion communicated to the pendulum No. 2; when, to his surprise, he found the clock going, and the pendulum to describe an arch of 3°, whereas at the same time No. 1 did not move 4°. In about half an hour after, No. 1 stopped, and the motion of No. 2 was increased to very near 5°. He then stopped No. 2 a second time, and set No. 1 a-going, as before; and standing to observe them, he presently found the pendulum of No. 2 begin to move, and the motion to increase gradually, till in 17m. 40s. it described an arch of 2° 10′, at which time the wheel discharging itself of the pallets, the clock went.

The arches of the vibrations continued to increase, till, as in the former experiment, the pendulum moved 5°; the motion of the pendulum No. 1, gradually decreasing all the while, as the other increased; and in three quarters of an hour after, it stopped.

He then left the pendulum of No. 1 at rest, and set No. 2 a-going, making it describe an arch of 5°; it continued to vibrate less and less, till it described but about 3°; in which arch it continued to move all the time he observed it, which was several hours. The pendulum of No. 1 seemed but little affected by the motion of No. 2.

Mr. E. tried these experiments several times over, without finding any remarkable difference. The freer the room was from any motion, as people walking about in it, &c. he found the experiments to succeed the better; and once he found No. 2 set a-going in 16m. 20s. and No. 1 at that time stopped in 36m. 40s.

Further observations and experiments concerning the two Clocks above-mentioned.

By the same.

The seemingly different effects which the two clocks had on each other, Mr. Elliscott accounts for as follows.

The manner in which the motion is communicated to the pendulum at rest, he conceives to be thus: as the pendulums are very heavy, when either of them is set a-going, it occasions by its vibrations a very small motion, not only in the case the clock is fixed in, but in a greater or less degree, in every thing it touches; and this motion is communicated to the other clock by means of the rail, against which both the cases bear. The motion thus communicated, which is too small to be discovered but by means of some such like experiments as these, may be judged by many insufficient to make so heavy a pendulum describe an arch of 2°, or large enough to set the work a-going; and indeed it would be so, but for the very great freedom with which the pendulum is made to move, arising from the manner in which it is hung. This appears from the very small weight required to keep it going, which, when the clock was first put together, was little more than 1lb. And if the weight was taken off, and the pendulum made to swing 2°, it would make 1200 vibrations before it decreased half a degree, so that it would not lose the 3000th part of an inch in each vibration. Indeed if the weight was hung on, the friction would be increased, and the pendulum would not move quite so freely; but even in that case it was found to lose but little more than the 2000th part of an inch, or about three seconds of a degree, in one vibration; and therefore if the motion communicated to it from the other, will make it describe an arch exceeding 3″, the vibrations must continually increase till the work is set a-going. And that the motion is communicated in the manner above supposed, is confirmed by the following experiments:

A prop was set against the back of the case of No. 2, to prevent its bearing against the rail; and No. 1 was set a-going: then observing them for several hours, Mr. E. could not perceive the least motion communicated to No. 2. He then set both the clocks a-going, and they continued going several hours; but he could not find they had any influence on each other. Instead of the prop against the back of the case, he put wedges under the bottoms of both the cases, to prevent their bearing against the rail; and stuck a piece of wood between them, just tight enough to support its own weight. Then setting No. 1 a-going, the influence was so much increased, that No. 2 was set a-going in less than six minutes, and No. 1 stopped in about six minutes after. In order to try what difference would arise, if the clocks were fixed on a

more solid floor, he placed them, exactly in the same manner as in the last experiment, on the stone pavement under the piazzas of the Royal Exchange, and stuck the piece of wood between them, as before; and setting No. 1 a-going, the only difference was, that it was fifteen minutes before No. 2 was set a-going, and No. 1 continued going near an half hour before it stopped.

From these experiments Mr. E. thinks it plainly appears, that the pendulum which is put in motion, as it moves towards either side of the case, makes the pressure on the feet of the case to be unequal, and, by its weight, occasions a small bearing or motion in the case on that side towards which the pendulum is moving; and which, by the interposition of any solid body, will be communicated to the other clock, whose pendulum was left at rest. The only objection to this, he conceives, is the different effects which the two pendulums seemed to have on each other. But this he hopes to explain to satisfaction.

For, notwithstanding these different effects, he soon found, by several experiments, that the two clocks mutually affected each other, and in the same manner, though not with equal force; and that the varieties observed in their actions on each other, arose from the unequal lengths of their pendulums only.

For, on moving one of the clocks to another part of the room, and setting them both a-going, he found that No. 2 gained of No. 1, about 1m. 36s. in twenty-four hours. Then fixing both against the rail, as at first, he set them a-going, and made the pendulums to vibrate about 4°; but he soon observed that of No. 1. to increase, and that of No. 2 to decrease; and in a short time it did not describe an arch large enough to keep the wheels in motion. In a little time after it began to increase again, and in a few minutes it described an arch of 2°, and the clock went. Its vibrations continued to increase for a considerable time, but it never vibrated 4°, as when first set a-going. While the vibrations of No. 2 increased, those of No. 1 decreased, till the clock stopped, and the pendulum did not describe an arch of more than 1° 30′. It then began to increase again, and No. 2 decreased, and stopped a second time, but was set a-going again, as before. After this No. 1 stopped a second time, and the vibrations continued to decrease till the pendulum was almost at rest. It afterwards increased a smaller matter, but not sufficiently to set the work a-going. But No. 2 continued going, its pendulum describing an arch of about 3°.

Finding them to act mutually and alternately on each other, Mr. E. set them both a-going a second time, and made the pendulums describe as large arches as the cases would permit. During this experiment, as in the former, he sometimes found the one, and at other times the contrary pendulum, to make the largest vibration.. But as they had so large a quantity of motion given them as first, neither of them lost so much during the period it was acted on by the other, as to have its work stopped, but both continued going for several days, without varying one second from each other; though when at a distance, as was before observed, they varied 1m. 36s. in twenty-hours. While they continued thus going together, he compared them with a third clock, and found that No. 1 went 1m. 17s. faster, and No. 2 went 19s. slower, than they did when placed at a distance, so as to have no influence on each other.

On altering the lengths of the pendulums, the period in which their motions increased and decreased, by their mutual action on each other, was changed; and would be prolonged as the pendulums came nearer to an equality, which, from the nature of the action, it was reasonable to expect it would. This discovers the reason why the pendulum of No. 2, when left at rest, would be set a-going by the motion of No. 1; whereas if No. 1 was left at rest, it would not be set a-going again by the motion of No. 2.

For he found, by several experiments, that the same pendulum, when kept in motion by a weight, would go faster, than when it only moved by its own gravity. On this principle, which may easily be accounted for, it follows, that during the time in which the shortest pendulum, No. 2, was only acted on by No. 1, it would move slower, and the times of its vibrations approach nearer to an equality with those of No. 1, than after it came to be kept in motion by the weight; and by this means the time which No. 1 would continue to act on it, would be prolonged, and be more than was required to make the pendulum describe an arch sufficient to set the work a-going. But, on the contrary, while the pendulum of No. 1, which was the longest, was only acted on by No. 2, as it would move slower, the difference of the times of the vibrations would be increased; and consequently the time which No. 2 would continue to act on it, would for this cause be shortened, so that before the pendulum of No. 1 would describe an arch sufficient to set the work a-going, the period of its being

acted on would be ended, and it would begin to act on No. 2; at which time its vibrations would immediately decrease, and continue to do so till it came to be almost at rest. And thus it would continue, sometimes to move more, and at other times less, but never sufficiently to set the clock a-going.

[*Phil. Trans.* 1739.

In summer, the thermometer being at 20°, Bianconi observed, that seventy-six vibrations of the pendulum elapsed while a sound passed over thirteen miles; in winter seventy-nine seconds, the thermometer being at 1.2°. In a cloud or mist 155″ elapsed while the sound passed and re-passed. Hence the air should expand $\frac{1}{70}$ for 21.2°, or $\frac{1}{270}$ for 1° of the thermometer employed, probably Reaumur's, which is $\frac{1}{608}$ for 1° of Fahrenheit.

Chladni infers, from the longitudinal vibration of different substances a velocity of 7,800 feet in a second, in tin; 9,300 in silver; 12,500 in copper; 17,500 in glass and iron; from 11,000 to 18,000 in wood; from 10,000 to 12,000 in tobacco pipes. His observations are fully confirmed by calculations from different grounds. According to the elasticity of fir, as inferred from an experiment of Mr. Leslie, the velocity of an impulse should be 17,800.

Most, perhaps all, gases, are mediums of sound, and by their change of temperature produce sound. This is particularly the case with hydrogen gas. Aqueous vapour, that of ether, and of phosphorus acid, produce a similar, but slighter, effect.

[*Bianconi. Brugnatelli. Chladni. Delarive. Young.*

END OF VOL. IV.

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